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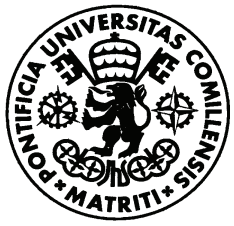

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PROYECTO FIN DE CARRERA

LINUX-DRIVER DEVELOPMENT FOR COMPONENTS OF THE UAV-BASED FAWN DETECTION SYSTEM

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Resumen

1.1. Introducción

1.1.1. Motivación

Cada año mueren sólamente en Alemania unos 100,000 cervatillos recién nacidos y alrededor de 500,000 animales salvajes incluyendo conejos, zorros e incluso pájaros [1]. Estos hechos suceden entre mayo y junio, coincidiendo la época de cosecha con el nacimiento de las nuevas crías.

Durante las primeras semanas de vida, las madres dejan a las crías en los campos, escondidas entre la hierba alta, mientras van a buscar comida. Los cervatillos reaccionan institivamente ante el peligro tumbándose y encondiéndose entre la hierba. Su falta de movimiento, su camuflaje natural y su pequeño tamaño dificultan su detección, siendo imposible para el agricultor verlos desde la máquina cosechadora.

Desde la agencia aeroespacial alemana (DLR) se están desarrollando diversos métodos para detectar los cervatillos en el campo antes de que pase la máquina cosechadora. Uno de estos métodos consiste en usar un octocóptero que sobrevuele el campo buscando dichos animales, como muestra la Figura 1.1.

Figura 1.1: Octocóptero volando

El octocóptero lleva a bordo, entre otros sensores, dos cámaras, una en rango visible y otra en infrarrojo, conectadas a ordenadores que analizan las imágenes obtenidas. Una vez se ha detectado el animal, se envía la posición exacta a otro ordenador que se encuentra en tierra. Desde

la centralita en tierra se pueden observar también en tiempo real las imágenes de las cámaras. Esto es útil no sólo para corroborar la detección de animales, sino también para comprobar que la imagen obtenida por la cámara térmica es válida, pues es sensible a las condiciones climatológicas y puede ser necesario tener que reajustar la configuración durante el vuelo.

1.1.2. Tarea asignada

El objetivo principal del proyecto es desarrollar el software necesario para configurar la cámara térmica y obtener las medidas del sensor de distancia que lleva a bordo el octocóptero.

Tanto la cámara como el sensor pueden conectarse a través del puerto serie. El ordenador a bordo no cuenta con más puertos serie disponibles. Sin embargo, cuenta con un bus I^2C que admite hasta 128 dispositivos conectados.

Para llevar a cabo dicha conexión, es necesario usar una interfaz que haga la conversión UART $\leftrightarrow$ I^2C. El dispositivo usado es el chip SC16IS740 [2]. En la Figura 1.2 se destaca tanto la conexión entre la cámara térmica (IR Camera) y el ordenador a bordo (Computer-On-Module) como la conexión entre el sensor de distacia (LDS) y el ordenador. Ambas conexiones se realizan mediante el conversor UART $\leftrightarrow$ I^2C.

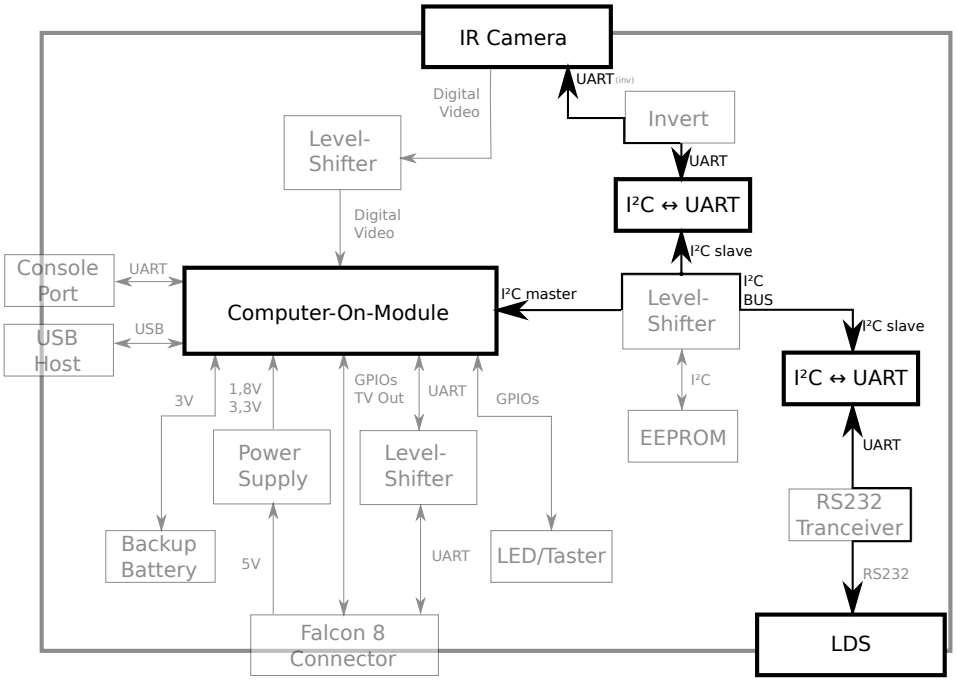

Figura 1.2: Diagrama de las conexiones entre los diversos dispositivos y el ordenador a bordo del octocóptero, destacando los componentes importantes para el software desarrollado para el proyecto.

El ordenador a bordo usa como sistema operativo Gumstix Overo Series, que incluye un kernel Linux. Debido a que no hay drivers disponibles para la interfaz SC16IS740 en Linux, el software desarrollado en el proyecto debe incluir un driver capaz de manejar dicha interfaz.

1.2. Metodología

En kernels monolíticos como Linux, tanto el kernel como todas las subrutinas encargadas de manejar directamente el hardware se ejecutan en el llamado "kernel space". Las demás aplicaciones encargadas de interactuar con el usuario se ejecutan en el llamado "user space". Estas aplicaciones sólo pueden interaccionar con el hardware mediante las funciones provistas a través del "kernel space" [3].

El software requerido debe actuar como puente entre el usuario y el dispositivo que quiera controlar, ya sea la cámara como el sensor. De esta manera es necesario desarrollar dos tipos distintos de software para cada dispositivo:

- Por un lado es necesario desarrollar un driver que envíe mensajes a través del bus I2C, configure y controle el conversor UART $\leftrightarrow$ I2C.
- Por otro lado, hay que desarrollar una aplicación personalizada para cada dispositivo que controle los mensajes que se le envían, lea la respuesta, y se la haga llegar al usuario.

A continuación se explica el desarrollo de ambos tipos de software:

1.2.1. Desarrollo del driver en "kernel space"

El driver cuenta con dos partes importantes. Por un lado, para proveer las funciones para el "user space" necesita contener un character driver. Por otro lado, debe comunicarse con el dispositivo a través del bus I^2C. Esto puede realizarse usando un i2c driver del i2c core perteneciente al kernel de Linux [3].

El driver desarrollado se inserta en el kernel mediante insmod. Esto ejecuta una función del driver llamada module_init(). En dicha función se procede al registro del character driver en el kernel y del i2c driver en el i2c core. El driver puede ser asímismo retirado del kernel mediante rmmod, que ejecuta la función module_exit().

Cuando el i2c driver es registrado en el i2c core, éste ejecuta unas determinadas funciones llamadas probe(), attach_device() y detect_client(). El driver desarrollado se encarga de recopilar la información concerniente al bus y la dirección del conversor durante la ejecución de dichas funciones, y la almacena en una estructura llamada i2c_client.

El character driver posee una estructura llamada file_operations con funciones como open(), close(), write() y read() que pueden ser usadas por aplicaciones. Dichas funciones deben definirse en el "kernel space". El driver es desarrollado de manera que en open() se configura la interfaz UART $\leftrightarrow$ I^2C de acuerdo a la configuración del puerto serie del dispositivo al que está conectado. Tanto open() como write() y read() usan la estructura i2c_client y las funciones provistas por el i2c core para poder comunicarse a través del bus I^2C.

La Figura 1.3 muestra cómo interactúan las estructuras más relevantes dentro del driver.

1.2.2. Desarrollo de la aplicación en "user space"

Para cada dispositivo se desarrolló una aplicación personalizada. Ambas aplicaciones tienen la misma estructura. Primero se crea un mensaje que pueda ser reconocido por el dispositivo. Después se usan las funciones open(), write() y read() para respectivamente configurar el conversor, enviar el mensaje y leer la respuesta. La respuesta es analizada y en caso de detectarse algún error vuelve a enviarse el mensaje al dispositivo hasta un máximo de tres veces. Tanto la respuesta definitiva como los errores en caso de haberlos son reportados al usuario. Antes de cerrarse la aplicación ejecuta la función close() del driver.

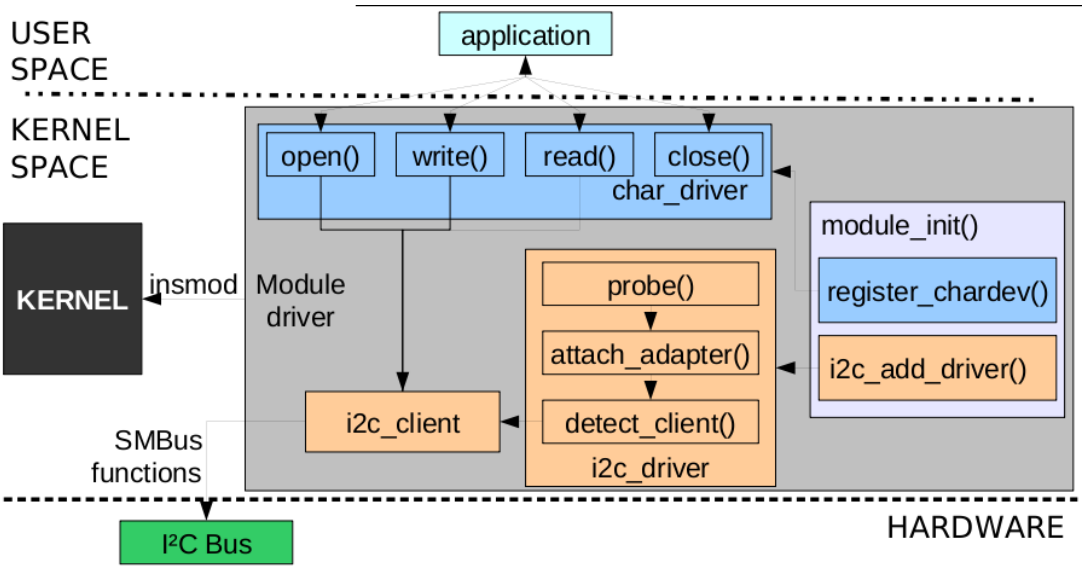

Figura 1.3: Estructura del driver desarrollado

La cámara admite un código hexadecimal con doble código de comprobación de errores. Esta codificación es muy poco intuitiva para el usuario, por ello en la aplicación se ha desarrollado un traductor que convierte mensajes del formato "parámetro valor" a dicho código, y genera automáticamente el código de comprobación. Igualmente analiza en la respuesta que no haya habido errores de transmisión y que la cámara haya ejecutado sin problemas el mensaje.

El sensor de distancia es más simple al admitir sólo caracteres que indican si debe realizar una medida o si debe cambiar entre modo normal y modo de baja energía. La aplicación desarrollada se encarga de "despertar" al sensor antes de cada medición y volver a dejarlo en modo de baja energía antes de cerrar la aplicación. De este modo se intenta consumir el mínimo posible de batería para que la autonomía de vuelo se vea mínimamente afectada.

1.3. Resultados

Para poder comprobar el funcionamiento del software, primero debe insertarse el driver en el kernel mediante insmod tau640.ko para la cámara e insmod mlr100.ko para el sensor.

La aplicación de la cámara se ejecuta con comandos que siguen la estructura ./configtau640 parametro valor. La lista con los parametros y rango de valores admitidos por la aplicación se encuentra en el anexo C de la memoria. La aplicación fue probada conectando un monitor a la salida de vídeo de la cámara y comprobando que efectivamente la imagen cambiaba de acuerdo a los comandos introducidos. Como ejemplo, en la Figura 1.4 se muestran diversas capturas tras probar los valores para el contraste 20, 50 y 70, y debajo de estas líneas se encuentra un ejemplo del funcionamiento de la aplicación:

```
root@overo# ./configtau640 contrast 100
     Sent: 6e 0 014 0 2605a 0642c22
     Answer: 6e 0 014 0 2605a 0642c22
```

Figura 1.4: De izquierda a derecha, imágenes capturadas por la cámara tras cambiar el contraste a los valores 20, 50 y 70

El funcionamiento de la aplicación del sensor se comprobó tomando medidas con el sensor conectado al ordenador a bordo. Todas las pruebas fueron satisfactorias comprobando que la aplicación funciona. A continuación se muestra un ejemplo del funcionamiento de la aplicación:

```
root@overo# ./mlr100 g
     2.04m
```

1.4. Conclusiones

El objetivo del proyecto es desarrollar el software necesario para controlar la cámara térmica y el sensor de distancia que lleva a bordo el octocóptero. Dicho objetivo se completó desarrollando para cada dispositivo un driver que controle directamente el hardware y una aplicación que interactúe con el usuario y maneje el driver.

Referencias

[1] Jarnemo, A. (2002). Wildlife Biology, vol. 8. Roe deer Capreolus capreolus fawns and mowing-mortality rates and countermeasures.

[2] SC16IS740/750/760. Single UART with I2C-bus/SPI interface, 64 bytes of transmit and receive FIFOs, IrDA SIR built-in support. NXP Semiconductors.

[3] Venkateswaran, Sreekrishnan (2008). Essential linux device drivers. Prentice Hall.

LINUX-DRIVER DEVELOPMENT FOR COMPONENTS OF THE UAV-BASED FAWN DETECTION SYSTEM

1.1. Introduction

1.1.1. Motivation

Every year, circa 100,000 roe deer fawns are killed by the harvesting machines during mowing actions in Germany, and a total of around 500,000 wild animals die every year in these conditions [1]. It happens mostly between May and June, coinciding the end of the growing seasons with the period when the baby deer are born.

The mother leaves the new born fawns in the high grass hidden from their natural predator while looking for food. During the first three to eight weeks of life, roe deer fawns face danger situations by remaining instinctively motionless on the ground. The lack of motion, their natural camouflage and their small size make their detection more difficult.

In order to locate those animals before the mowing, the German Aerospace Center (DLR) through the Remote Sensing Technology Institute is developing several systems aimed to scan an area looking automatically for the fawns. One of those methods consists in using an octocopter that flies over the field looking for those animals, as Figure 1.5 shows.

Figure 1.5: Octocopter flying over a field

The octocopter carries several sensors and cameras on board. The cameras are a thermal camera and a visible camera. Both are connected to a Computer-On-Module that analyzes the images. Once an animal is detected, the computer sends the exact position to another computer on the ground. From this computer it is also possible to observe the images taken by the cameras in real time. This is useful not only to corroborate the detection of the animals, but also for checking that the image taken by the infrared camera is valid for the analysis. This image depends on the weather conditions and it is usually necessary to readjust the parameters of the camera during the flight.

1.1.2. Assigned task

The task of this master thesis consists in developing the necessary drivers that enables the communication between the Computer-On-Module and the thermal-camera and between the Computer-On-Module and the laser distance sensor.

The thermal camera as well as the sensor can communicate through a serial port. The Computer-On-Module has no more serial ports availables. However, it has a I^2C bus that admits up to 128 I^2C devices connected.

In order to establish this connection, it is necessary to add a UART $\leftrightarrow$ I^2C converter. The chosen interface is the chip SC16IS740 [2]. Figure 1.6 shows the connections between the components and the computer in the expansion board, and emphasizes the important connectios for the developed software.

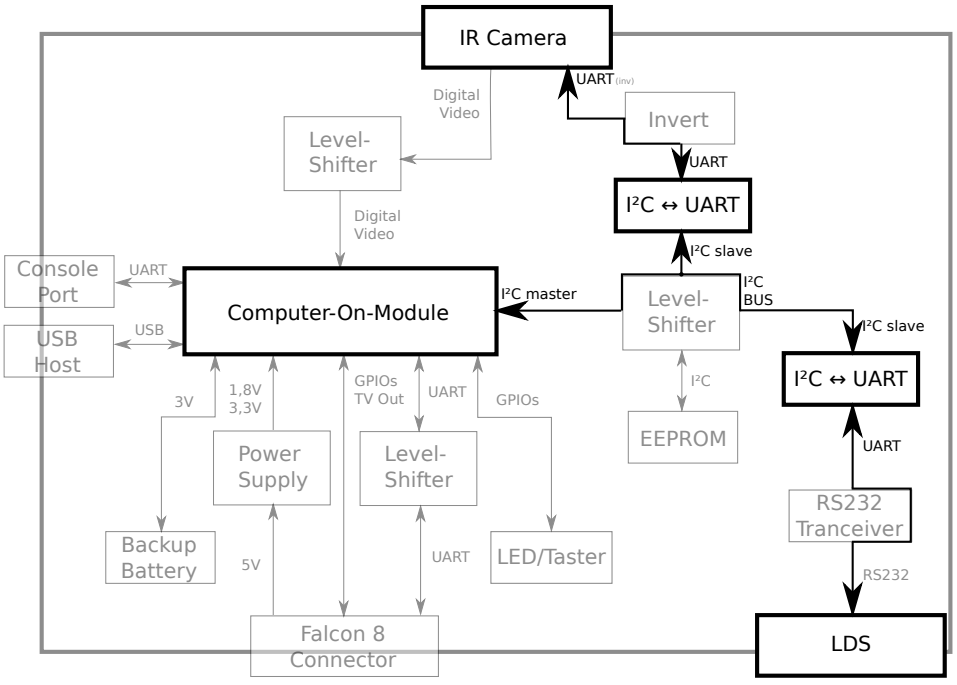

Figure 1.6: Connection between the COM and both the thermal camera and the laser-distance sensor

The Computer-On-Module uses Gumstix Overo Series as operating system, that already includes a Linux kernel. As there is no driver for the SC16IS740 in Linux, it is necessary to develop a driver to manage the interface and include it in the software.

1.2. Methodology

In monolithic kernels as Linux, the kernel runs in kernel mode and the applications in user mode. Any subroutines or functions forming part of the kernel (modules and device drivers, for example) are considered to be part of "kernel space". End-user programs are part of the user space. When these applications need to interact with the systemâs hardware, they donât do so directly, but through the kernel supported functions [3].

The required software musts act like bridge between the user and the corresponding device. Therefore it has been established that the software will be split in two parts:

- a module driver in the kernel space to configure the serial port of the UART $\leftrightarrow$ I^2C converter and to control the device,
- an application in the user space to interact with the user, personalized for each device.

Hereafter follows an explanation of the development of the software.

1.2.1. Development of the linux-driver

For this certain situation, there are two important structures required in the driver. On the one hand, the struct file_operations is typically used to manipulate files. As in UNIX or Linux systems the devices are seen as files that can be open, closed, written and read, it will be used in this case to manipulate the device. On the other hand, it is needed an i2c_client to hold the information of the i^2c device. The kernel already provides some tools collected in the i2c_core to use the i^2c port, and by adding an i2c_driver with probe and detach functions to bind and unbind the device, the communication through the i2c port will be easily attained. Therefore it is necessary to attach the file_operations to the character device, and to register an i2c_driver in the i2c_core [3].

The developed driver is inserted with the kernel using the command $insmod. It executes the function of the module driver called module_init(). The task of this function is to register the char_driver with the kernel and the i2c_driver in the i2c_core. The driver can also be deleted from the kernel using rmmod, which executes the function module_exit() of the module driver.

Once the i2c_driver is registered in the i2c core, it executes certain functions called probe(), attach_device() and detect_client(). The driver collects information about the I2C bus and the address of the I^2C slave together into the struct i2c_client.

The character driver provides the struct file_operations with functions as open(), close(), write() and read() that can be used by the applications in "user space". Those functions must be however defined in "kernel space". In open() the driver configures the serial port of the UART $\leftrightarrow$ I^2C interface in accordance wirh the serial port of the attached device. The open() function as well as write() and read() use the struct i2c_client and the functions provided by the i2c_core in order to establish the communication through the i2c port.

Figure 1.7 shows the interaction between the relevant structs of the developed software.

1.2.2. Development of the applications for "user space"

Although a personalized application was developed for each device, both contain the same structure. First the application creates a valid message for the device. Later the functions open(), write() and read() are respectively used for configuring the interface, send the message and read the answer. The answer is analyzed, and in case of detecting an error, the message is sent again to the device a maximal of three times. The result as well as the possible error are reported to

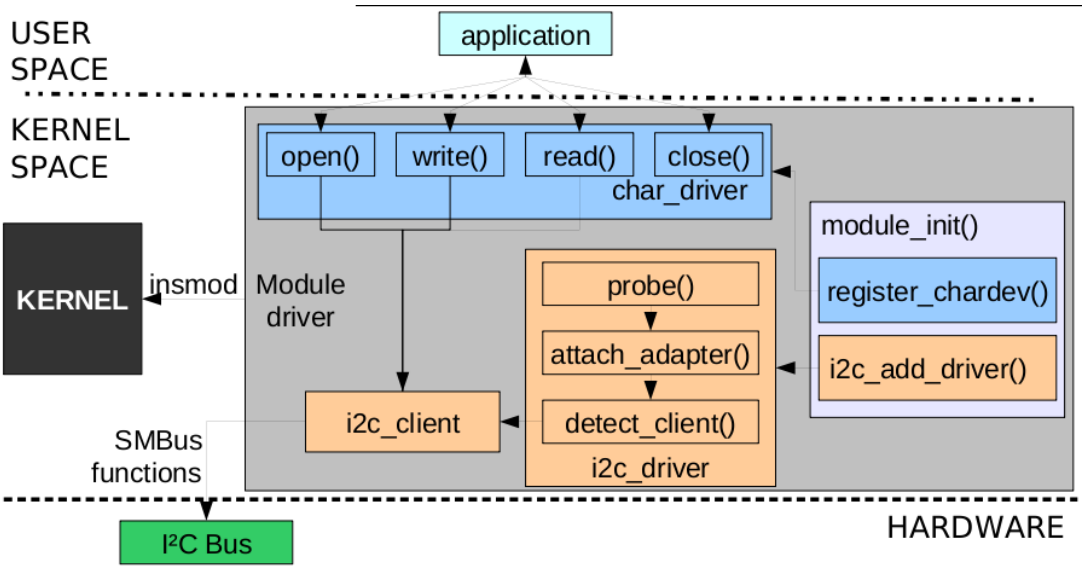

Figure 1.7: Diagram of the interaction between relevant structs in the developed module driver

the user. Before closing the application, the function close() belonging to the module driver is executed.

The thermal camera admits a very particular hexadecimal code with double cyclic redundancy check code. This encoding is not quite user-friendly, therefore the application was developed with a translator from messages with the format "parameter value" to the aforementioned code, and also generates automatically the check code. It analyzes as well the answer from the device looking for transmission errors or problems in the status of the camera.

The laser distance sensor is much simpler as it only admits characters indicating if the sensor must take a new measurement or change between the normal power mode and the lower power mode. The sensor can only take measures while the normal power mode is activated. Because of that, the developed application set the sensor in normal power mode before asking for the measure.

After receiving the answer from the sensor, the device is set in lower power mode in order to reduce the consumed power to minimal.

1.3. Results

In order to test the developed software it is necessary to insert first both drivers with the kernel, using insmod tau640.ko for the camera and insmod mlr100.ko for the sensor.

The application of the camera is executed using the structure ./configtau640 parameter value. A list with all the parameters and values range admitted by the application for the thermal camera is allocated in Appendix C on the report of the thesis. The application was tested connecting a monitor to the video output of the camera, and checking that the entered commands actually change the image in an expected way. Figure 1.8 helps to visualize the difference between three different contrast values in the image captured by the camera, and the following code is an example of setting the contrast with the value 100:

```
root@overo# ./configtau640 contrast 100
      Sent: 6e 0 014 0 2605a 0642c22
      Answer: 6e 0 014 0 2605a 0642c22
```

Figure 1.8: From left to right, captured images with contrast 20, 50 and 70

The application for the laser distance sensor was tested by taking measurements with the sensor connected to the Computer-On-Module. All the tests resulted satisfactory proving that the application works correctly. The following code is an example of the application taking measurements:

```
root@overo# ./mlr100 g
        2.04m
```

1.4. Conclusions

Aim of the thesis was to developed the required software for controlling the thermal camera and laser distance sensor at the octocopter. The mentioned aim was full filled developing a driver that controls the communication with the device and a personalized application for eah device that interacts with the user and manages the developed driver.

Bibliography

[1] Jarnemo, A. (2002). Wildlife Biology, vol. 8. Roe deer Capreolus capreolus fawns and mowing-mortality rates and countermeasures.

[2] SC16IS740/750/760. Single UART with I2C-bus/SPI interface, 64 bytes of transmit and receive FIFOs, IrDA SIR built-in support. NXP Semiconductors.

[3] Venkateswaran, Sreekrishnan (2008). Essential linux device drivers. Prentice Hall.

Abstract

Every year, just in Germany around 100,000 roe deer fawns are killed by the harvesting machines during the mowing actions [JARNEMO, 2002]. During the silage, the carcasses of those animals is accidentally mixed with the crop and given as fodder for the dairy cattle, producing them a paralytic illness. This fact harms the agrarian sector by causing huge economical losses.

The German Aerospace Center (DLR) is developing several systems aimed to scan an area looking automatically for the fawns [ISRAEL, 2010a]. One of those methods is using an UAV (unmanned aerial vehicle) based system that carries a computer-on-module with several sensors, including a thermal infrared camera, a RGB-camera and a laser-distance sensor.

The main scope of this master thesis consists in developing the necessary drivers that enables the communication between the computer-on-module and:

1. the thermal-camera
2. the laser-distance sensor

The communication is not direct. An interface that converts from UART to I^2C connects the serial port of each sensor with the computer-on-module via I^2C bus. The driver must manage the added interface and act like a bridge between the user and the sensors.

An application for each sensor is also developed, in order to facilitate the user to control both devices.

A mis padres, por ayudarme a cumplir mis objetivos como persona y estudiante, por brindarme los recursos necesarios, confiar en mis decisiones y haberme aconsejado siempre que lo he necesitado.
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DOCUMENT I

REPORT

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List of Abbreviations

A/D	Analog/Digital
ACK	Acknowledge
API	Application programming interface
BC	Byte Count
CCITT	International Telegraph and Telephone Consultative Committee
CH	Channel
CMOS	Complementary Metal Oxide Semiconductor
COM	Computer-on-module
CR	Carriage Return
CRC	Cyclic Redundancy Check
CTS	Clear To Send
DLH	Divisor Latch MSB
DLL	Divisor Latch LSB
EB	Expansion-board
EN	Enable
I^2C	Inter-Integrated Circuit
ICAI	Insitituto Católico de Artes e Industrias
IR	Infrared
IrDA	Infrared Data Association
FC	Function Code
FCR	FIFO Control Register
FFC	Flat-Flex Cable
FIFO	First In First Out
GND	Ground
GPIO	General Purpose Input Output
GPS	Global Position System
GUI	Graphic User Interface
LCR	Line Control Register
LDISC	Line Discipline
LDS	Laser-distance sensor
LF	Line Feed
LSB	Less Significant Bit
LVDS	Low-voltage differential signaling
MMC	Multimedia Card
MSB	Most Significant Bit
NA	Negative Acknowledge
OE	OpenEmbedded
OS	Operating System
OTG	On-The-Go
PC	Personal Computer

PCB	Printed circuit board
PFC	Proyecto Fin de Carrera
PWM	Pulse-Width Modulation
RGB	Red, green and blue
RTS	Request To Send
RX	Receive
SCL	Serial Clock
SDA	Serial Data
SMBus	System Management Bus
SPI	Serial Peripheral Interface
TTL	Transistor-transistor Logic
TTY	Teletypewritter
TX	Transmit
UART	Universal Asynchronous Receiver Transmitter
USB	Universal Serial Bus

PART I

REPORT

Chapter 1

Introduction

1.1. Problem situation and motivation

Every year, circa 100,000 roe deer fawns are killed by the harvesting machines during mowing actions in Germany [JARNEMO, 2002]. A total of around 500,000 wild animals die every year in these conditions [CERRA, 2009]. It happens mostly between May and June, coinciding the end of the growing seasons with the period when the baby deer are born. The mother leaves the new born fawns in the high grass hidden from their natural predator while looking for food. During the first three to eight weeks of life, roe deer fawns face danger situations by remaining instinctively motionless on the ground. The lack of motion, their natural camouflage and their small size make their detection more difficult.

Other animals like rabbits and brooding birds are also victims of the harvesting machines. Even for adult wild animals it is difficult to escape from the commonly operating width of 6-14 meters and the operating speed of 12-20 km/h [KURT, 1968]. For the agriculturist it is impossible to detect the fawns from the harvesting machine, and this situation leads to a distressful death of the animals [MUERI, 1999, ISRAEL, 2010a].

During the silage the carcasses of those animals is mixed with the crop, and later it is given as fodder for the dairy cattle.

Temperatures over 25° C within a protein-full hermetically sealed environment conforms an ideal culture medium for the "Clostridium botulinum" bacterium. This bacterium produces the "Botulinum toxin", which is considered the most powerful neurotoxin ever discovered. An amount between 0.1 and 1 micrograms of this protein is enough to kill an adult person. Getting the carcass into the harvest, keeping it inside a silo and getting warm because of the fermentation fulfills the requirements that create the poison [HOLZHAUER, 2009].

Once the dairy cattle consume the contaminated fodder, they get a paralytic illness called "Botulism". This kind of intoxication is usually deadly and not directly treatable. In a dairy farm this could mean the death of the animal, or in extreme cases the death of the whole herd. The economical losses are huge for the farm.

From an economical and also moral point of view, it is necessary to develop a system capable of detecting the roe deer fawns in time.

1.2. Previous methods of resolution

Several methods to avoid the killing of those animals during the harvest were proven, in order to let the agriculturist mow their field risk-less. The following methods of resolution were so far prosecuted:

- **Mechanical rescue-system mounted at the mowing machine**

  Years ago a mechanical device with the form of tines was attached in the front of the mower, preventing the machine taking the wild animals by lifting them instead and therefore saving them. This method is no longer effective nor found in today's agriculture technology. Instead nowadays it is used a horizontal arm with pipes or chains vertically attached that sweeps the following lane flushing out the wild animals.

- **Combing with dogs**

  Another option is scanning the field before mowing. Dogs are really useful in this case because of their sense of smell, and they can be trained to perceive the smell of the deer fawns and then scare them. This method has however a disadvantage. It takes a lot of time to trail a whole field, even with multiple searchers. The aggravating factor of the geometrical conditions showed in Figure 1.1 should be also taken into account. At an average vegetation height of one meter, a 0.3 meter long deer fawn can be found by a 1.7 meter tall searcher if it is inside a radius of 0.5 meters. The higher the grass is, the more difficult it is to find the fawn. If there is grass over the fawn, even just being half a meter away might not be enough.

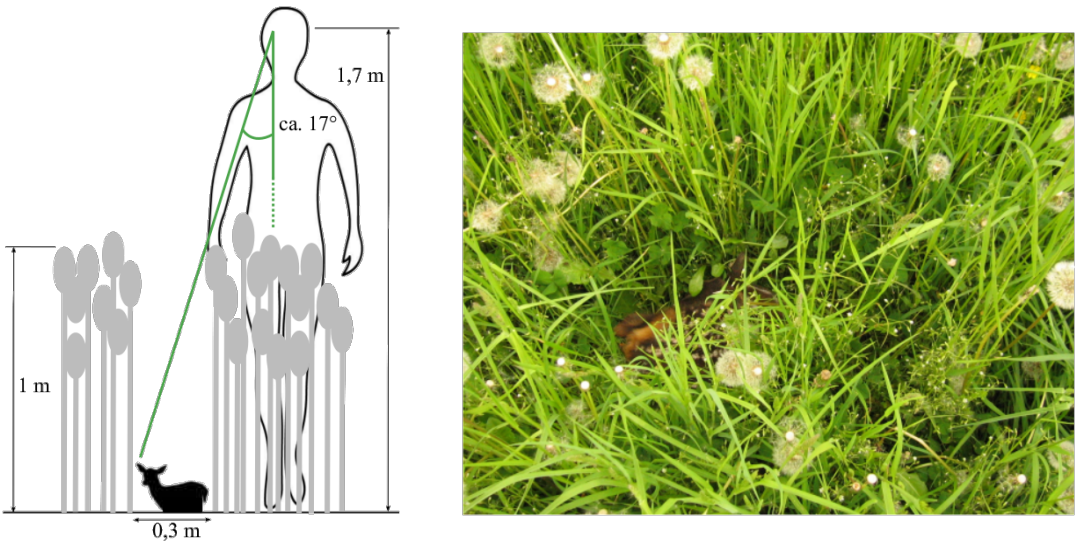


Figure 1.1: Geometrical conditions in the search of deer fawn. To find it, the person must be in a close proximity from 1 to 2 meters (Source: [ISRAEL, 2011a]).

In order to locate those animals before the mowing, the German Aerospace Center (DLR) through the Remote Sensing Technology Institute is developing several systems aimed to scan an area looking automatically for the fawns. [ISRAEL, 2010a]

- **Portable rescue-system**

  DLR developed and patented a portable rescue-system in 1987. Ten years ago it was introduced in the market by i_s_a[1]. The rescue-system consists of a telescopic handle that, thanks to ten infrared sensors, can be used to cover a width of six meters, as shown in Fig 1.2. This system can quickly scan the closer ground. On cloudy days or during the early morning and late evening, the system works with a high reliability. On the other hand, with a strong sunlight the sensors will be limited and fawns can no longer be distinguished from other objects (such as mounds or molehills).

[1] distribution by: isa Industrieelektronik GmbH | www.isaweiden.de | www.wildretter.de

Figure 1.2: People carrying the portable rescue-system (Source: [HARDER, 2008])

- **Extension arm / sensors at the mowing machine**

  More recent developments and researches engage in adding appropriate sensors directly to the agricultural machine, as shown in Figure 1.3. The first prototype is a cantilever arm, mounted on the mower, that scans the following swath looking for wild animals from a height of 1.2 meters. The signal is processed before the mower reaches the scanned swath.

  In the experiment shown in Figure 1.4, infrared sensors, microwave sensors, distance sensors, infrared cameras and cameras with visible spectral range are combined for this purpose. Experience has shown that a camera-based system is unfavorably because of the high-speed of the mowing machine considering the low height it is assembled at and the vibrations caused by the terrain. Infrared, microwave and proximity sensors look more promising and therefore will be traced.

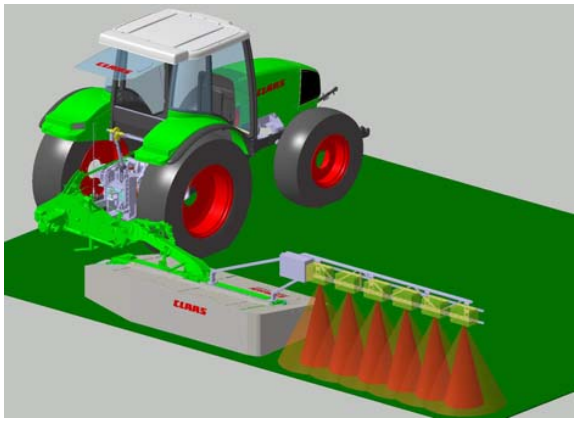


Figure 1.3: Design of mower with extension arm (Source: [ISRAEL, 2010b])

Figure 1.4: Testing model of extension arm incorporated in mower (Source: [ISRAEL, 2010a])

Microwave sensors can detect objects that contain a considerable amount of water. The extension arm uses this kind of sensors to detect deer fawns in the swath of grassland. The sensor has a certain angle of incidence, as shown in Figure 1.5, to detect the reflected

waves. The slope angle has as advantage that the receptor won't receive the reflected microwaves from the ground or puddles, but isolated objects as deer fawns can be easily distinguished from ground and therefore detected.

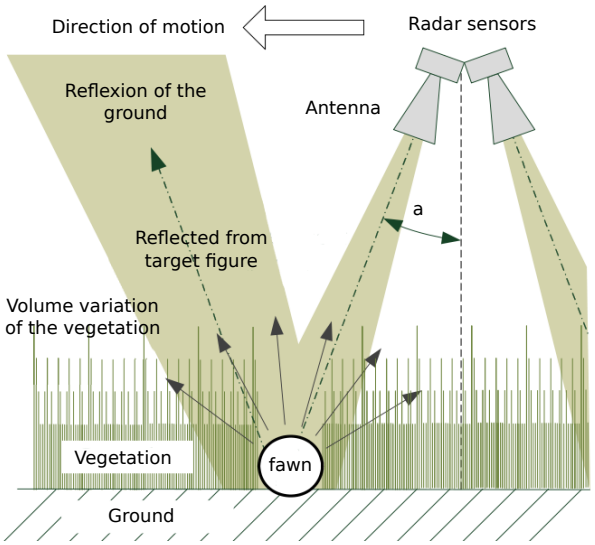


Figure 1.5: Principle of the double-radar (Source: [A. FACKELMEIER, 2009])

Another possibility is to assemble the sensors directly on the mowing machine with a front-facing orientation looking at the current swath. The geometrical problem explained in the "Trailing with dogs" section would be also applied here, reaching the conclusion that placing infrared sensors is more effective than a camera system in order to detect a fawn lying on the ground.

- **UAV-based system**

  The last method consists in using an UAV (unmanned aerial vehicle) based system that carries a computer-on-module with several sensors. The main sensors of the measurement hardware on board are a thermal infrared camera and a camera for the visible region. Under certain weather conditions it is difficult to distinguish in the infrared image an animal from something else that reflects the solar light. The visible camera is used to compare both images in order to make the detection more precise.

  The cruising altitude can be chosen between 30 meters and 50 meters. As Fig. 1.6 shows, at an altitude of 50 meters the images taken from the UAV cover an area of 27 meter of diameter. This reduces significantly the necessary time to track the whole field. Weather conditions determine the optimal moment for harvesting the field. Therefore, under certain conditions, a whole region can be harvested in a few days. In this case time is crucial to track as much terrain as possible.

  The UAV plans the flight with the help of a GPS and the Google Maps Elevation API. In order to verify the accuracy of the API, it is also equipped with a laser distance sensor for measuring the distance to the ground during the flight. This is also important because the UAV is programmed to fly always at the same altitude taking as reference the start position. In sloping terrains the actual distance to the ground can change, as shown in Fig. 1.7, and therefore the scale of the image would be different. For the image processing it is essential to know the actual scale of the image.

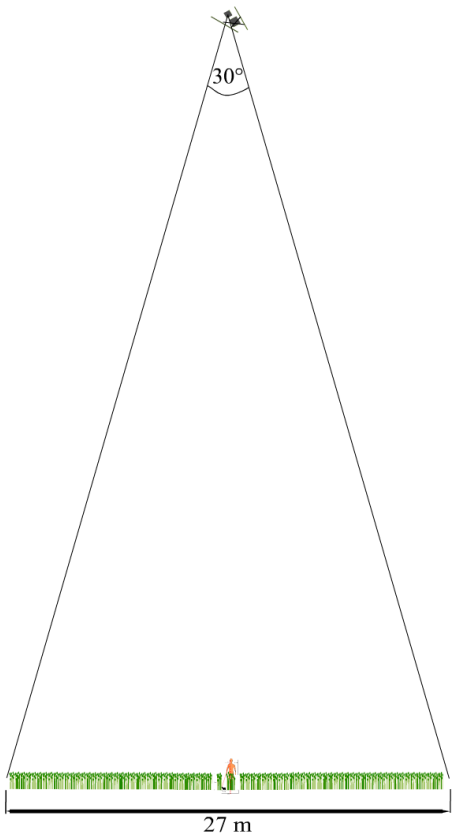


Figure 1.6: Terrain covered by the UAV when flying at an altitude of 50 meters (Source: [ISRAEL, 2011a]).

1.3. UAV-based fawn detection system

This project is focused in the development of software for the UAV-based fawn detection system.

The vehicle uses as main structure the Octocopter Falcon 8 developed by Ascending Technologies GmbH. The core of the detection-system is a small computer-on-module (COM) which takes over the data-processing. A thermal and a RGB-camera are the main sensors attached to the system. In general all sensors are connected to the COM through an expansion-board (EB).

Hereafter follows a more detailed description of the components.

1.3.1. Octocopter platform

The platform of the UAV is an octocopter system developed by Ascending Technologies GmbH [2]. The called Falcon 8 model is specially designed for air-photography and to inspect and get data during the flight. The model flying can be seen in Fig. 1.8.

The eight actuators (combination of rotor and motor) give the UAV a high stability and skill to hold winds with a maximal speed of 10 m/s. The stability is reinforced by an integrated control system, using the measures of multiple electronic sensors like a GPS, gyroscope, barometric height sensors, compass and velocity sensors.

[2] http://www.asctec.de

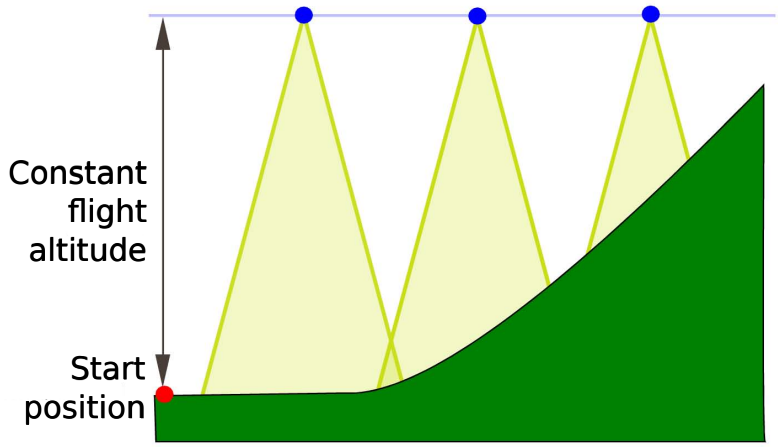


Figure 1.7: The flight-plan of the UAV is designed to fly always at the same altitude taking as reference the start position. In sloping terrains this affects to the image processing as the scale changes (Source: [ISRAEL, 2011a]).

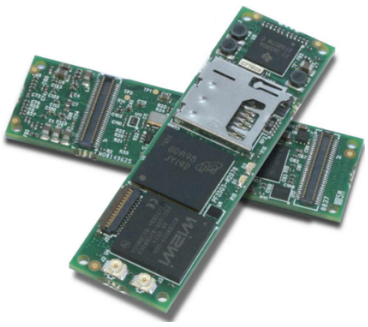
Figure 1.8: Falcon 8 model flying over a field (Source: [ISRAEL, 2011b])

The octocopter includes also an autopilot software developed by AscTec, that in combination with the waypoint planning software developed by DLR allows the UAV to fly over a given area scanning efficiently the terrain.

1.3.2. Hardware components

1. **Computer-on-module**

The core of the measure system is a small Computer-on-module (COM) developed by Gumstix [3]. Its specifications are detailed in Figure 1.9



- **Processor** OMAP35xx with Cortex-A8
- **CPU velocity** 600 MHz or 720 MHz
- **Memory** 512 MB or 256 MB Low-Power DDR RAM; 256 MB NAND Flash
- **On the board** Micro SD Slot
- **Dimensions** 58 mm x 17 mm x 4.4 mm
- **Weight** 6 g

Figure 1.9: Gumstix Overo COM (Source: www.gumstix.com)

The COM counts with one 27-pin Flat-Flex Cable (FFC) connection, which is located on the upper side of the module and provides a digital video interface for connection of cameras, two u.fl antenna connectors and two 70-pin AVX 5602 Board-To-Board Connectors that makes a total of 140 signals for GPIOs, I^2C, 6 PWM lines, 6 A/D, 1-wire, UART, SPI, Extra MMC lines, Headset, Microphone, Backup battery, High Speed USB Host and USB OTG.

2. **Thermal-camera**

   The thermal camera is the model TAU 640 from the company FLIR Commercial Systems [4]. This camera covers almost the whole long-wavelength infrared region detecting wavelengths from 8 to 14 μm.

   Configuration and remote control is provided via a RS-232 serial interface consisting of signals named RX, TX and GND using 3.3 volt signal levels. Outgoing messages are only generated as a response of each incoming command. The serial port settings are shown in Table 1.1.

   The real-time digital video is provided by a digital parallel channel. The XP-Bus may be configured through software for three different digital data channels:

   - The **BT.656** channel transmits pixels in a video data signal format called YUV, that contains image, symbol, and color information.
   - The **CMOS** channel is a parallel image data output. The raw-data are directly sent, not requiring transference or conversion via a video capture card.
   - The serial low-voltage differential signaling (**LVDS**). This channel consists of three signal lines: a clock, a composite sync (frame sync and data valid), and serial data.

   The camera is connected to the computer-on-module through two communication lines. The RS-232 serial interface used for the configuration is connected through a UART-I^2C converter (SC16IS740) to one of the I^2C connectors of the COM. The digital video data travels through the 27-pin Flat-Flex Cable (FFC) connection. The chosen digital data channel will be the BT.656.

[3] http://www.gumstix.com
[4] http://www.flir.com/cvs/cores/view/?id=51374

Parameter	Value
Baud rate	57600
Data bits	8
Parity	None
Stop bits	1
Flow control	None

Table 1.1: Port settings of the RS-232 serial interface of the camera TAU 640

3. **RGB-camera**

   It is also necessary to add a RGB-camera to the octocopter in order to collect color pictures to contrast them with the infrared ones. The choice is a 5 megapixels camera (e-CAM50_OMAP_GSTIX) from e-con Systems, specifically developed and built for the COM of the Gumstix's Overo Series. The configuration is done through an I^2C interface and, as happens with the thermal camera, the video data travels through the 27-pin Flat-Flex Cable (FFC) connection. In order to let both thermal camera and RGB-camera use the FFC, a 2:1 multiplexer controlled by the COM will choose which data the Gumstix system will receive and analyze.

4. **Laser-distance sensor**

   The laser-distance sensor (LDS) will be used to measure the height at which the octocopter is flying, in order to verify the accuracy of the Google Maps Elevation API. The chosen sensor is the model MLR100 developed by Aerius Photonics, LLC. It has a long range capability from $\sim$0 m to 100 m with a resolution better than 20 cm. The LDS is connected through a RS-232 serial interface to the I^2C Bus from the COM. In order to make this connection capable, a UART-I^2C converter (SC16IS740) will be used.

5. **Expansion-Board**

   In order to connect the COM with the remaining hardware components, it was necessary to develop an expansion-board (EB). The task was carried out during a previous master thesis [NEUGEBAUER, 2011]. For its design several factors had been considered.

   From the structural side, the optimization resides in the minimum weight and size as well as an optimal physical distribution of the components all along the expansion-board.

   Because of the different specifications of the elements in the EB and the other hardware components, it was also necessary to implement level-shifters, inverters and converters.

   Another important factor in the design is the power supply. The required voltage changes from one element to another, making it necessary the existence of 1.8V, 3.3V and 5V sources. The EB is fed with a voltage supply of 5V. Internal voltage converters provide the remaining 3.3V and 1.8V. In the octocopter the power supply comes from a lithium polymer battery.

   Figure 1.10 shows the block diagram of the EB.

An overall front and back picture with the components assembled is shown in figure 1.11

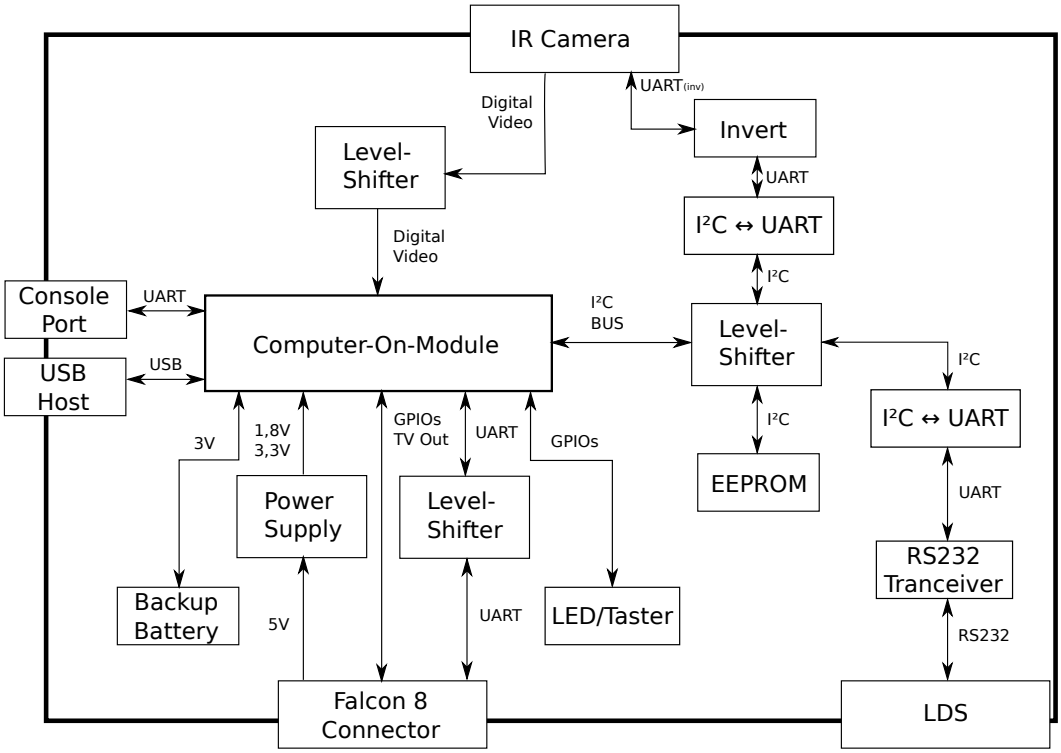


Figure 1.10: Block diagram of the Expansion-Board

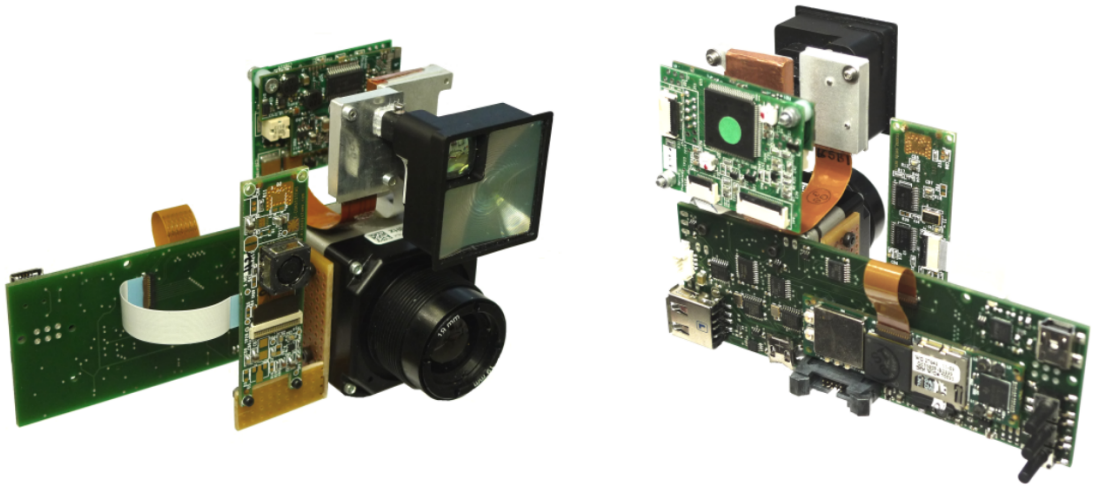


Figure 1.11: Front and back picture of the EB with all components assembled (Source: [NEUGEBAUER, 2011])

1.3.3. Software

The Gumstix Overo Series uses the Linux Kernel Image 2.6.34 and provides a software bundle and a base system out-of-the-box (i.e. it doesn't require any additional installation). It also utilizes a build environment with cross-compilation support called Linux® OpenEmbedded (OE), that creates Linux distributions by producing root file systems, packages and custom software,

and can build many of existing open source libraries and tools useful on and for embedded systems.

The heart of OE is Bitbake, a tool that resolves dependencies between different software packages in order to build a complete embedded system. For that purpose the tool needs a basic recipe consisting of a configuration file with information about the sources, the dependencies as well as some options the compilation and the installation need. The OE environment uses this information in order to assemble the package to the complete build system.

A more detailed explanation about how the cross compiler works and how it was used for the development of the drivers can be found in section 2.2.4 Cross Compiler.

1.4. Assignment situation and task structuring

The task of this master thesis consists in developing the necessary drivers that enables the communication between the COM and the thermal-camera and between the COM and the laser-distance sensor.

The need of this communication stems from two different reasons. On the one hand, the height of the sun, certain weather conditions and the terrain characteristics have influence on the parameters of the thermal camera such as to optimize the detection of deer fawns. Therefore the parameters need to be often readjusted. On the other hand, as explained before in Fig. 1.7, it is important to know the scale of an image when processing it. In sloping terrains the height at which the image is taken can vary, affecting the scale.

The connection of both components to the COM is not direct. Both devices can only communicate through serial ports, but there are no more available UART connections at the COM, so it becomes necessary to find another way to connect both devices to other ports of the COM. With the help of a UART-to-I^2C converter the components can be connected to the still available I^2C ports of the COM. The responsible chip for the conversion is the SC16IS740 interface [SC1, 2011]. Figure 1.12 marks the relevant hardware for the task.

Therefore the software must be executed in the Gumstix System that uses the Linux Kernel, and it must be capable of communicating with the SC16IS740 through the I^2C-bus, configuring the serial port of the chip and establishing a communication with the attached device.

Before developing the software some preliminary work is necessary. First of all it is recommended to test the SC16IS740 interface alone. This task is achieved by connecting both sides of the interface to a computer. Besides there is also a software environment and some tools required for the development of software for the Gumstix System. The necessary software and hardware to achieve the test, as well as the software tools required to later develop the software, are explained in Chapter 2.

The next step is developing the software. In monolithic kernels as Linux, the kernel runs in kernel mode and the applications in user mode. Therefore it has been established that the software will be split in two parts:

- a driver in the kernel space to control the device. It controls the communication with the hardware and configures the port setting of the UART at the SC16IS740.
- an application in the user space to interact with the user. It is personalized for each device.

The information of how the software is developed remains in Chapter 3. The obtained results are explained in Chapter 4. User manuals for the drivers and applications developed lies as appendixes. Appendix 1 explains how to configure the serial port settings in driver for the SC16IS740. Appendix 2 explains how to develop an application for both drivers. Appendix 3 contains the commands for the application developed for the TAU640 camera. Appendix

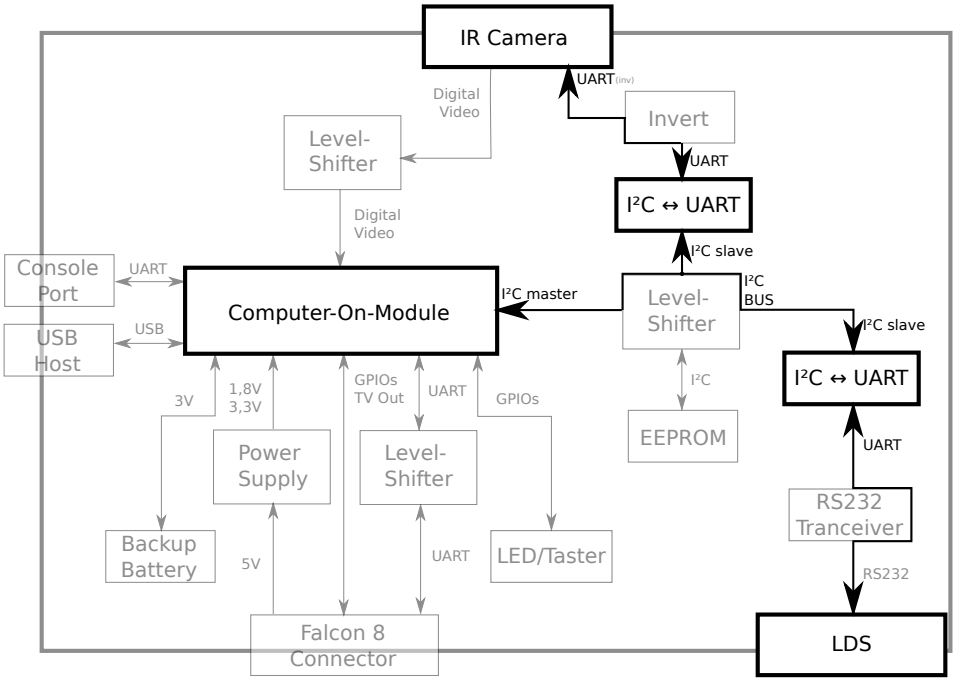


Figure 1.12: Connection between the COM and both the thermal camera and the laser-distance sensor

4 contains the allowed arguments for the application developed for the laser-distance sensor MLR100.

Chapter 2

Development of the test environment

Before starting developing the software, some preliminary tasks were required. This chapter contains the previous preparation, that includes the required software environment and both hardware and software tools to test the device.

The first task is to test the SC16IS740 interface by connecting it to a PC. For that purpose, it was necessary to add some hardware devices as converters and level-shifters, and to use a terminal program to establish the communication. The idea is to test first the outputs of some specific entries, and then to connect the devices for which the driver will be programmed in order to find the correct way to send the commands and to check the reaction of the device as well as the response.

Once the chip is tested, the second task is to program, and some software tools where used for achieving that purpose. Although it is possible to compile code directly in Gumstix, for large projects it is more comfortable to use cross-compilation or the OpenEmbedded Cross build system. This way it can be developed from a PC and then tested in the Overo System. The tests were carried out thanks to a communication software tool.

All the previous preparations to the development of the software are explained in detail below.

2.1. Hardware tools

The SC16IS740 is an interface that enables a bidirectional protocol conversion from UART to I^2C. The operating voltage can be either 3.3 V or 2.5 V. It also provides internal registers, a 64 bytes FIFO buffer and supports a fully bidirectional RS-485. Further technical specifications of the device are explained in section 3.1.

The easiest way to test the behavior is to connect both ports (UART and I^2C) to a PC using on one side a UART-USB and on the other side a USB-I2C converter, as shown in figure 2.1.

A terminal program executed in the computer can be used to send commands through one port and read the converted output by checking the other port. The chosen terminal program for the test is HTerm.

It is important to check that the output data is correct, before further tests in this environment are done.

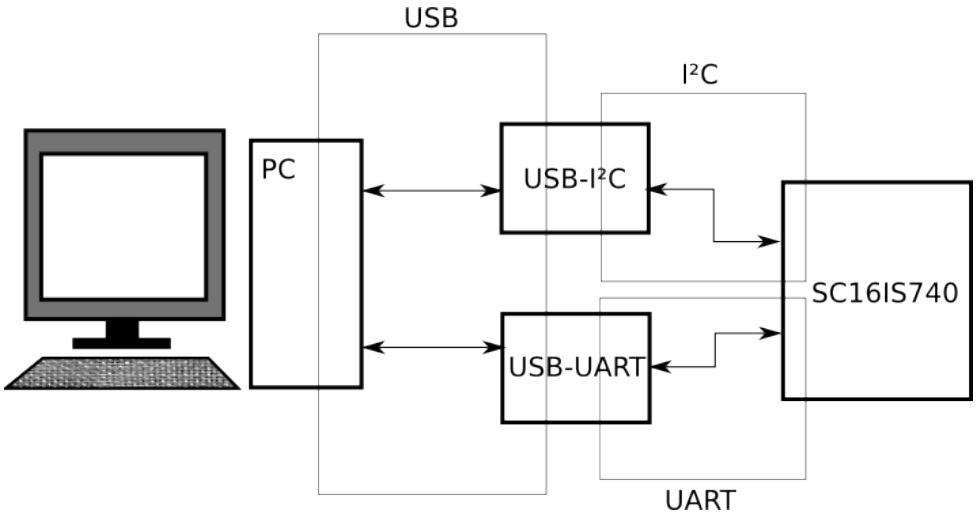


Figure 2.1: SC16IS740 connected to a PC using both USB-I2C and UART-USB converter

2.1.1. USB-I2C converter

In order to test the chip it is necessary to connect the I²C port of the SC16IS740 to a PC. The USB-I2C converter developed by ELV [5] (Fig. 2.2) was used for this purpose. The converter is provided with three I²C-Bus including a +5V source, and a USB port. Each I²C-Bus contains a clock signal (SCL), a line to send data through (SDA) and ground (GND). More information about the I²C protocol and the signals it requires can be found in section 3.1.1.

Figure 2.2: ELV USB-I2C (Source: [ELV, 2010])

As the I²C port at the USB-I2C works at 5 V and the SC16IS740 can only work with 3.3 V or 2.5 V, a level shifter between them is needed.

The PCA9517 [PCA, 2007] is a level translating I²C-bus repeater that provides level shifting between low voltage (0.9 V to 5.5 V) and higher voltage (2.7 V to 5.5 V) for I²C-bus applications.

The pin configuration in Figure 2.3 shows both I²C-bus sides with the corresponding SCL and SDA of each side, a ground (GND) pin, and it provides also an enable (EN) pin. The purpose

[5] http://www.elv.de/output/controller.aspx?cid=74&detail=10&detail2=24012

of the EN pin is to enable the repeater when it is connected to the same voltage level than V_{CCB}. The lower voltage I^{2}C-bus is represented as the A-side and the higher one as the B-side.

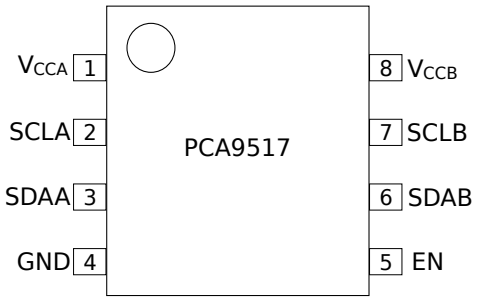


Figure 2.3: Pin configuration of the PCA9517

As the EN pin must be connected to a voltage supplier from the B-side, it was decided to set the SC16IS740 at the B-side and therefore the ELV USB-I2C to the A-side of the level-shifter. It was also necessary to add pull-up resistors (10 kΩ each) on the B-side. In Figure 2.4 are only shown the connection lines related with the I^{2}C-port.

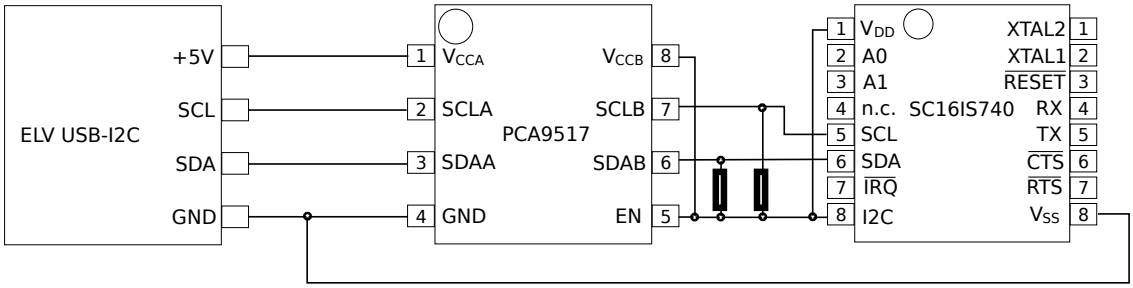


Figure 2.4: Connection lines only related with the I^{2}C-port of the circuit that connects the SC16IS740 chip with a PC

2.1.2. UART-USB converter

In order to connect the UART-port of the SC16IS740 chip to a computer, either a UART-USB converter or a UART-RS232 is required. For this project, the USB to TTL serial UART converter TTL-232R-PCB [TTL, 2010] developed by FTDI Chip was chosen.

The converter is a printed circuit board (PCB), which is USB powered and USB 2.0 full speed compatible. It provides six outputs for the UART, consisting of Tx, Rx, RTS#, CTS#, VCC and GND. Information about the outputs can be found in Table 2.1

The resistor configuration in the PCB gives the chance of setting the UART signal whether at +3.3V levels or +5V levels [TTL, 2010]. The more convenient choice is setting it at +3.3V, which is the operating voltage of the SC16IS740.

Figure 2.5 shows the circuit corresponding to the UART side. By combining the circuit related to the I^{2}C-port (Fig. 2.4) and this one (Fig. 2.5), the whole circuit to test the SC16IS740 is already complete.

Name	Type	Description
GND	GND	Device ground supply pin.
CTS#	Input	Clear to Send Control input / Handshake signal.
VCC	Output	+5V output,
TXD	Output	Transmit Asynchronous Data output.
RXD	Input	Receive Asynchronous Data input.
RTS#	Output	Request To Send Control Output / Handshake signal.

Table 2.1: TTL-232R-PCB Input / Output Descriptions

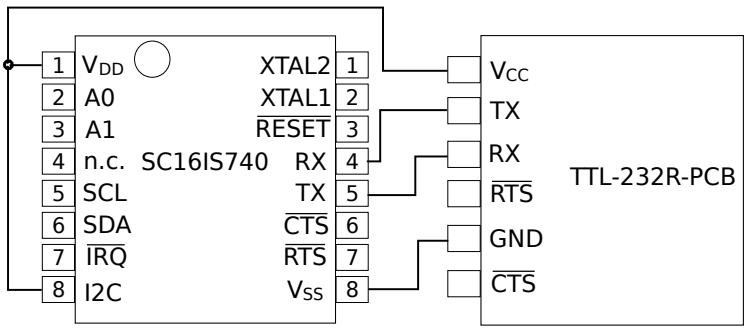


Figure 2.5: Connection lines only related with the UART of the circuit that connects the SC16IS740 chip with a PC

2.2. Software tools

Besides the hardware tools, some software tools and a software environment (see section 2.2.4 Cross Compilation) were also used to check the behavior of the chip and the devices.

Communication software tools (see section 2.2.1) were used to access and control the devices connected to the serial port from the PC, as well as a special GUI application developed for controlling the thermal camera (see section 2.2.2).

These software tools and their applications are explained in this section.

2.2.1. Communication tools

There are some applications that allow a communication with devices connected through the serial port. In this project two serial port terminal programs were used.

In order to access the COM and load the Gumstix Overo System, Kermit (2.2.1.1) was chosen because of recommendation for the Gumstix Over System.

During the tests, the communication with the other devices connected to the computer was established using a GUI application. For this project, HTerm (2.2.1.2) was chosen.

2.2.1.1. Kermit

Kermit is a computer file transfer/management protocol and a set of communications software tools that provides a consistent approach to file transfer, terminal emulation, script programming, and character set conversion across many different computer hardware and almost every OS platform [COLUMBIA UNIVERSITY COMPUTER CENTER, 2011].

It was used to load the Gumstix Overo and manipulate it from the personal computer. But first it is necessary to set manually the serial configuration. In GNU/Linux it can be easily done by saving the following commands in a file and then executing it [Gum, 2004-2011].

```
#!/usr/bin/kermit +
kermit -l /dev/ttyUSB0
set speed 115200
set reliable
fast
set carrier-watch off
set flow-control none
set prefixing all
set file type bin
set rec pack 4096
set send pack 4096
set window 5
connect
```

The above code defines /dev/ttyUSB0 as the location of the device. This location can obviously change depending on the devices connected to the computer. After executing it, if the Overo Board is correctly connected to the computer and once the power adapter is plugged, Gumstix will automatically boot.

2.2.1.2. HTerm

HTerm [HAMMER, 2008] is a GUI terminal program for real and virtual serial interfaces that works under Windows and Linux. As shown in Fig. 2.6 the connection is configurable and it helps to execute the test in a handy way. Beside the choice of the port, the other important given settings are:

- Baudrates from 300 to 256000 Bd
- Data: 5, 6, 7 or 8 bits per word
- Stop-bit: 1, 1.5 or 2
- Parity: none, even, odd, mark, space
- Gives the option of CTS flow control

The program was used to test the correct configuration of the SC16IS740 chip (3.1.3 UART configuration for the SC16IS740), as well as to try different inputs checking out the correctness of the output data. During the driver tests, several trials connecting the EB to the PC instead of to the corresponding device were done, because it eases the debugging process (see section 4.1.2).

2.2.2. TAU640 thermal camera connected to the computer

Before programming the application that helps to change the configuration of the camera, it is recommended to test first how the camera works. This is performed by connecting the thermal camera to a computer. To connect the camera to the PC, a UART-USB converter as the one explained in section 2.1.2 was needed.

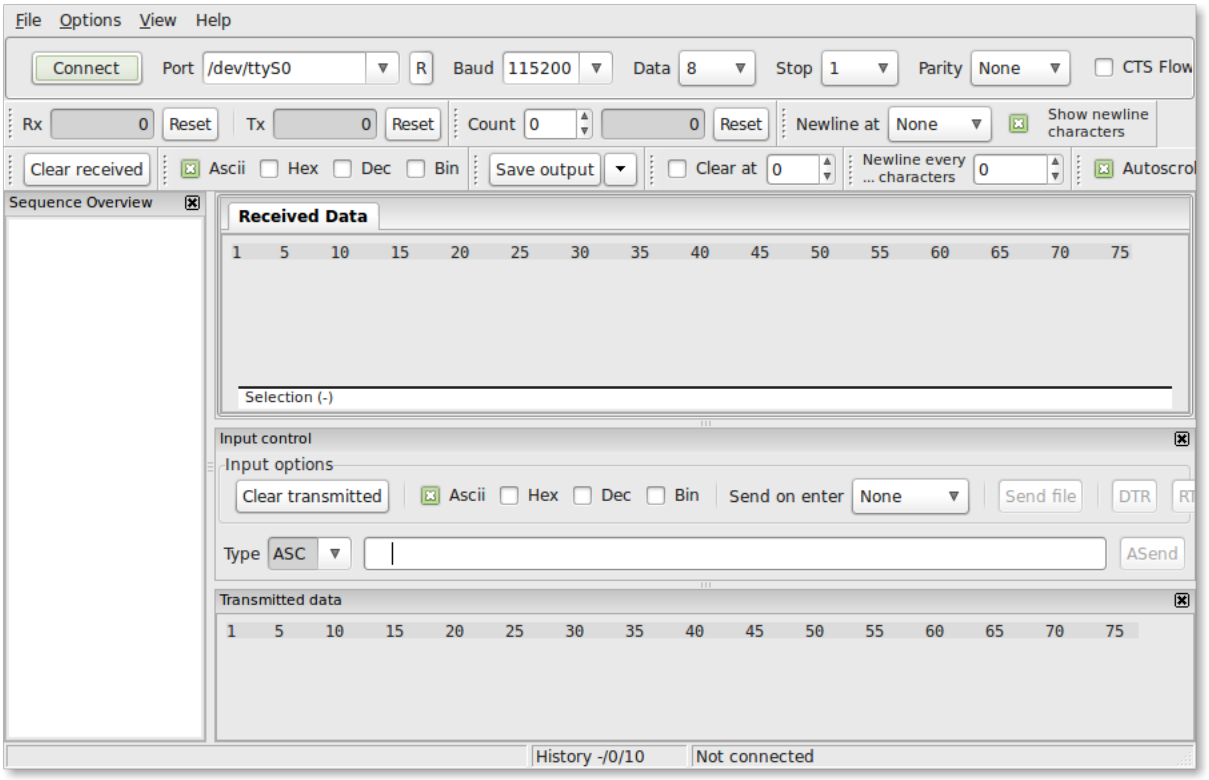


Figure 2.6: HTerm 0.8.1 beta

FLIR Systems has developed a software for controlling the camera from the PC connected through USB or RS-232 serial interface (FLIR Camera Controller GUI [SYSTEMS, 2011]). It was used to test the influence of different parameters in the resulting image.

Figure 2.7 shows the FLIR Camera Controller GUI with some features that can be set.

Once the more important parameters for the project are defined with the FLIR Camera Controller GUI, they can be implemented by using HTerm (see section 2.2.1.2) in order to try the special format of the commands accepted by the camera. Further information about the special format can be found in section 3.2.2.

The required configuration of the serial port in the thermal camera is:

- **Baud rate**: 57600
- **Data bits**: 8
- **Parity**: None
- **Stop bits**: 1
- **Flow control**: None

2.2.3. MLR100 laser distance sensor connected to the computer

The sensor is equipped with an Interface Adapter Board that allows UART and RS232 communication (see Figure 2.8). The UART interface uses a 3.3V signal but it is 5V tolerant. The admissible power supply may vary from 4V to 40V. The numbered pins in Fig. 2.8 are detailed in Table 2.2. The connection with the computer was achieved connecting pins 1 to 3 to the RS232 port of the computer and the power supply was obtained from a USB port.

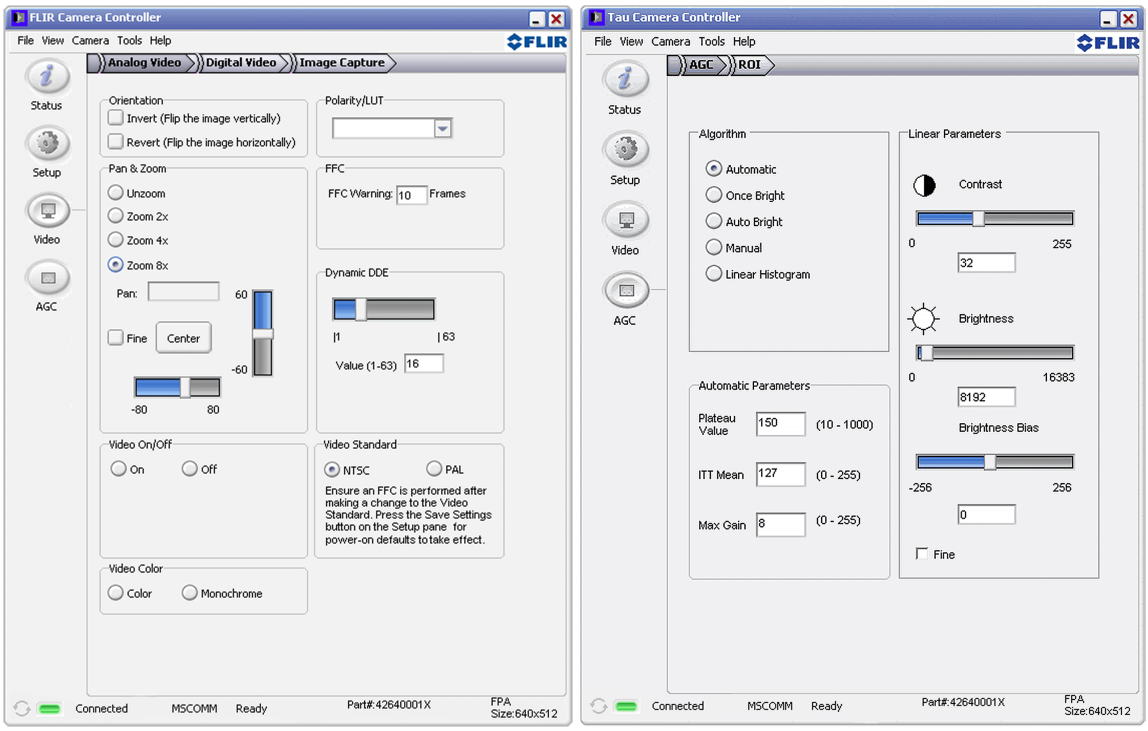


Figure 2.7: Setup Tab and AGC Tab of the FLIR Camera Controller GUI (Source: [Tau, October 2010])

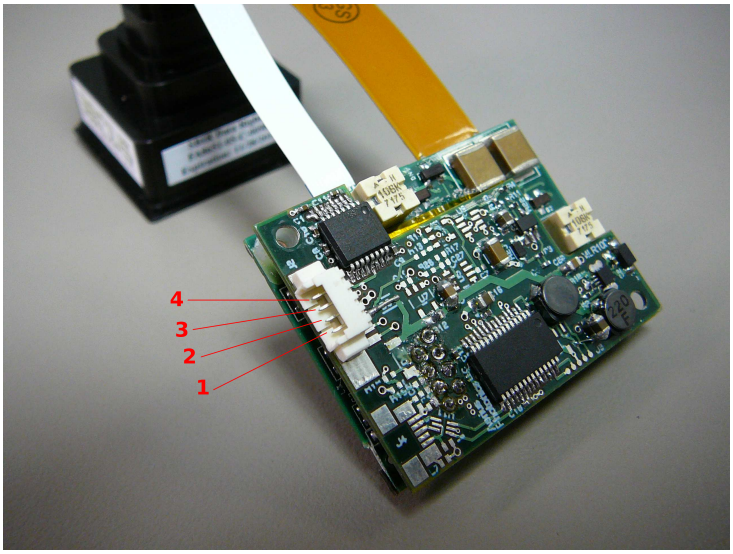


Figure 2.8: Interface Adapter Board of the MLR100 sensor with the pins from the UART numbered

There is already a GUI software developed by Aerius Photonics ("Aerius MLR PC Control Software" [Aer, 2009]) that allows PC control of the laser distance sensor MLR100. However, HTerm was used for testing the format of the inputs and outputs that the device allows.

The required configuration for the COM port is:

- **Baud rate**: 19200
- **Data bits**: 8
- **Parity**: None

Pin Number	Definition
1	Tx
2	Rx
3	Ground
4	Power (>= 4V, <=40V)

Table 2.2: Pin Definition for the connection between MLR100 and a PC

- **Stop bits**: 1
- **Flow control**: None

Transmitted characters must be followed with CR (in hexadecimal 0x0D). All answers ended with LF (in hexadecimal 0x0A). This is important for establishing the correct format of the sent and received data while programming the application.

2.2.4. Cross Compiler

A Cross Compiler is a compiler that creates executable code for another platform different from the one where the code is compiled. So it makes possible to develop software for an embedded system using a personal computer. In the case of the Gumstix Overo Series, the Linux® OpenEmbedded (OE) provides a build system. It contains a collection of BitBake "recipes". These recipes contain the source URL of the package, dependencies, and compile and install options. OE uses the information in these recipes to track dependencies, cross-compile the package, and create binary packages. It will also create complete images including boot loaders, kernel, and root file system. As a first step the framework will build a cross-compiler toolchain for the target platform.

Once the build environment is set, the directories are structured in a specific way:

```
 gumstix-oe
|-bitbake
|-build
|-org.openembedded.snapshot
|-com.gumstix.collection
|-user.collection
|-extras
`-tmp
```

From all the directories, only the most relevant ones for the development of the software are below explained [GUMSTIX, 2011b]:

- **bitbake** OpenEmbedded is based upon BitBake, a tool for executing tasks and managing metadata. This directory contains the BitBake tool and its associated configuration files.
- **build** The build directory contains configuration data for the build system. The configuration is split between three files, all of them in build/conf: auto.conf, local.conf, and site.conf. auto.conf is used primarily to specify what machine configuration the build is targeted toward. local.conf is used to specify build policy (uclibc vs glibc, debug vs release, etc) site.conf is used for general configuration (location of source code cache, location of temporary file directory, environment set up, parallel make, etc)

- **user.collection** This is the directory were the custom recipes should be placed. BitBake gives highest preference to the recipes in this directory, making it possible to override any functionality without having to touch directories under Gumstix source code control.
- **tmp** This is where the build system keeps its working files and also where it places the output of the build. From all the directories that it contains, it is worth pointing out sysroot. Inside tmp/sysroot there are the cross development tools for generating code for the Gumstix processor (compilers, linkers, etc.)

Some necessary paths must be defined in Makefile for building the kernel module:

```
OVEROTOP ?= /home/USER/overo-oe
CROSS_COMPILE ?= $(OVEROTOP)/tmp/sysroots/i686-linux/usr/armv7a/bin/
                                                    arm-angstrom-linux-gnueabi-
KERNEL_PATH ?= $(OVEROTOP)/tmp/sysroots/overo-angstrom-linux-gnueabi/kernel
ARCH ?= arm
```

Neither KERNEL_PATH nor ARCH are required for building user modules. As it will be clarified in next chapter, the required driver will actually have two parts. First there is a user application. The user will interact only with this application. In Linux a user application is not allowed to manage directly the system's hardware, but through the kernel supported functions. For that purpose another software must also be developed and inserted inside the kernel in order to interact between the app and the hardware.

Chapter 3

Development of the Linux-driver

Aim of the master's thesis is to program drivers for controlling the thermal camera and the laser distance sensor integrated in the octocopter. Both devices can only communicate through serial ports, but there are no more available UART connections at the COM, so it becomes necessary to find another way to connect both devices to other ports of the COM.

The SC16IS740 chip converts from UART to I^2C and the COM has still available I^2C ports. Once the chip is integrated in the EB, the aim turns to be on the one side to be able to communicate with the devices through the SC16IS740, and on the other side to manage to send commands on an understandable format for the device, and to make it easier for the user to control both devices.

In monolithic kernels as Linux, the kernel runs in kernel mode and the applications in user mode. Therefore it has been established that the software will be split in two parts:

- a character driver in the kernel space to control the device,
- an application in the user space to interact with the user.

Figure 3.1 helps to visualize this division.

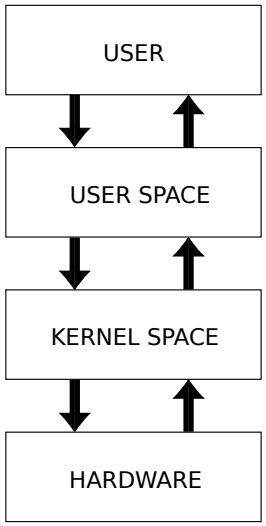


Figure 3.1: Interaction-layers between user and hardware

There are also other ways to achieve the aim. The most considered one was the creation of a terminal driver for the SC16IS740. The driver would be developed as a generic driver capable

of interacting with any SC16IS740 interface without depending on the characteristics of the attached device. For the user, the SC16IS740 interface would act like a serial port that needs to be configured for the specific attached device.

Instead of the generic driver, a particular software for each device (both the camera and the sensor) was developed. The software includes a character driver with the specific configuration for the serial port already set, and a personalized application for the corresponding attached device.

Figure 3.2 may clarify the difference between the driver actually developed and conceived generic serial driver.

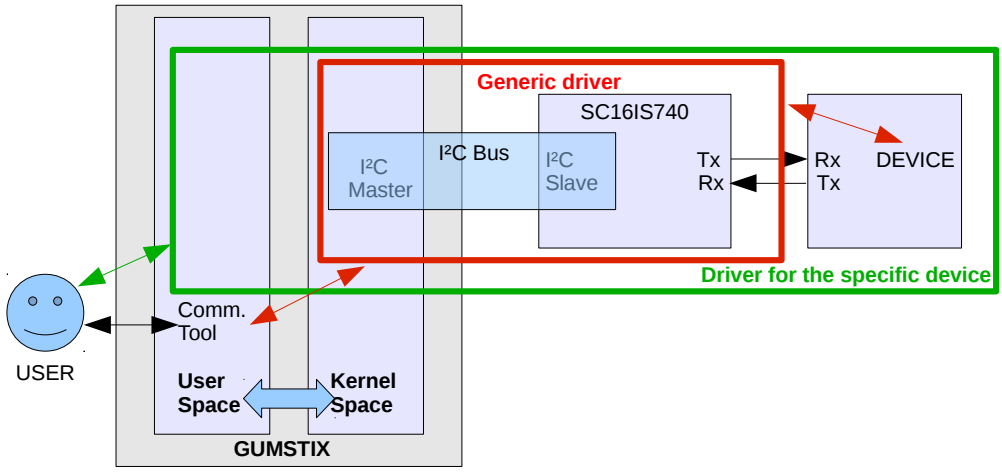


Figure 3.2: The aim of the generic driver is that the user can communicate through it as it were a serial port. The user would interact with the attached device using a communication tool (see section 2.2.1) that needs to be configured for the certain device attached to the chip.
The developed driver is specified for the attached device and manages it in an optimal way. The user interacts directly with the device through the application.

Hereafter follows a detailed description of the chip, its necessary configuration and the development of the driver as well in kernel space as in user space, and the steps to develop the generic terminal driver for the SC16IS740.

3.1. SC16IS740 Chip

The SC16IS740 is an interface that enables a bidirectional protocol conversion from UART to I^2C/SPI. The choice between the I2C-bus or the SPI interface depends of the voltage of the pin 8 (Fig 3.3) [SC1, 2011]. If the pin is at logic high, the I^2C-bus interface is selected. Logic low means the SPI interface is selected.

The chip is provided with a FIFO buffer that can store up to 64 characters (including three additional bits of error status per character for the receiver FIFO) from both the transmitter and receiver. To use it and relieving the host of excessive software overhead by buffering received/transmitted characters, the SC16IS740 needs to be placed in the FIFO mode. The way to enable the FIFO is explained in 3.1.3.

The Expansion-Board has two SC16IS740 integrated, one connected to the thermal camera and the other one to the laser distance sensor. Both are connected to the COM through the

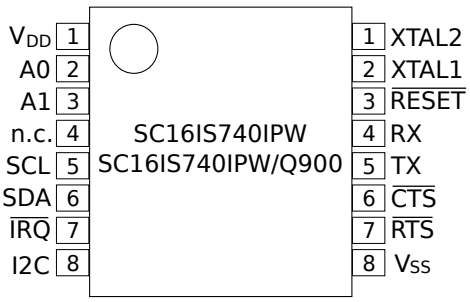


Figure 3.3: Pin configuration for TSSOP16 with I²C-bus interface

I²C-bus and to the corresponding device through the UART. The simple diagram circuit shown in Fig. 3.4 helps to visualize this connection.

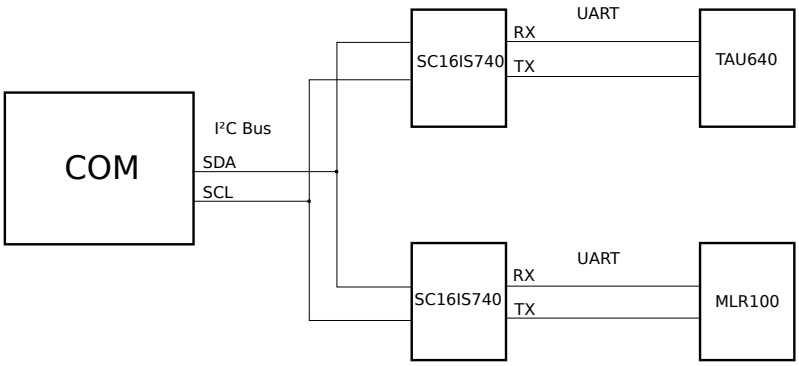


Figure 3.4: Connection between COM, SC16IS740 chips and the corresponding devices

Below it is explained how both protocols work and the specific configuration both chips need for having the wished behavior.

3.1.1. I²C

I²C (Inter-Integrated Circuit) is a serial computer bus invented by Phillips [NXP, 2012]. The bus uses a bidirectional two-wire connection consisting of the Serial Data Line (SDA) and the Serial Clock (SCL). A third line (GND) is also necessary but only for having the ground reference. The bus connects two nodes, the "master" and the "slave". The "master" device starts the data transmission, generates the clock signal, and chooses whether to read or to write the slave. Each slave has an assigned 7-bits address, this way a master can handle up to 128 slaves. Any node can play the master role as long as the device supports this feature. Common I²C bus bit rates are 100 kbit/s for standard mode and 10 kbit/s for low-speed mode.

When the master tries to write in a slave, the communication has the following format:

S	Slave address	W	ACK	Reg. address	ACK	DATA	...	ACK	P	idle

When the master reads the slave, the format of the communication looks as follows:

S	Slave address	W	ACK	Reg. address	ACK	S	Slave address	R	ACK

DATA	ACK	...	NACK	P	idle

The colored messages are the ones sent by the slave, the other ones are sent by the master. The meaning of the different messages and segments are explained in the following lines:

- **S** Start bit, it indicates that the master starts the communication by pulling SDA low while SCL remains at high level. In consequence, slaves get ready and wait for the beginning of the transaction.
- **Slave address**: 7-bit address [A7:A1] of the slave, sent from MSB to LSB.
- **W**: Occupies the position A0. When the master is trying to write it takes the value 0.
- **R**: Occupies the position A0. When the master is trying to read it takes the value 1.
- **ACK**: Acknowledge bit, confirms the reception of data. The receiver transmits a single 0 bit.
- **NACK**: Negatively acknowledge bit, indicates either there was an error during the reception or the master wants to finish the transmission. The receiver transmits a single 1 bit.
- **Register address**: 8-bit address that indicates to the slave to which register the master wants to access.
- **Data**: Data is sent in an 8-bit format.
- **P**: Stop bit, the master indicates the end of the communication by pulling SDA at high logic level while SCL remains at high level.
- **idle**: Both SDA and SCL are at logic high and any device can act as master.

In SC16IS740 the I^2C-bus interface can only work in slave mode. This means the Gumstix system must play the master role, and also that therefore the I^2C interface of the SC16IS740 chip needs an address. The address can be selected using the pins A0 and A1 (Fig. 3.3). Usually with two bits the options are reduced to four possible states. The SC16IS740 chip allows up to 16 addresses using four possible values for each pin. Table 3.1 shows the different combinations depending of the voltage values at pins A0 and A1. The chosen addresses for both SC16IS740 in the EB are:

	A7	A6	A5	A4	A3	A2	A1	A0
Laser distance sensor	1	0	0	1	0	0	0	R/W
Thermal camera	1	0	0	1	0	0	1	R/W

where [A7:A0] represents the bits of the address from MSB to LSB, and R/W distinguish if the order is for reading or writing, taking the value 1 or 0 respectively.

After selecting the address, the master also has to choose the register it is going to interact with. Table 3.2 shows how the address for the registers is built. In SC16IS740 the internal register has a 4-bits ID (A[3:0]). In Section 3.1.3 there are shown the address of the principal registers and those that need to be configured to make the interface work in the wished way.

A1	A0	SC16IS740 I2C addresses (hex)[1]
VDD	VDD	0x90 (1001 000X)
VDD	VSS	0x92 (1001 001X)
VDD	SCL	0x94 (1001 010X)
VDD	SDA	0x96 (1001 011X)
VSS	VDD	0x98 (1001 100X)
VSS	VSS	0x9A (1001 101X)
VSS	SCL	0x9C (1001 110X)
VSS	SDA	0x9E (1001 111X)
SCL	VDD	0xA0 (1010 000X)
SCL	VSS	0xA2 (1010 001X)
SCL	SCL	0xA4 (1010 010X)
SCL	SDA	0xA6 (1010 011X)
SDA	VDD	0xA8 (1010 100X)
SDA	VSS	0xAA (1010 101X)
SDA	SCL	0xAC (1010 110X)
SDA	SDA	0xAE (1010 111X)

[1] X = logic 0 for write cycle; X = logic 1 for read cycle.

Table 3.1: SC16IS740 address map [SC1, 2011]

Bit	Name	Function
7	-	not used
6:3	A[3:0]	UART's internal register select
2:1	CH1, CH0	channel select: CH1 = 0, CH0 = 0 Other values are reserved and should not be used.
0	-	not used

Table 3.2: SC16IS740 register address byte [SC1, 2011]

SMBus

SMBus (abbreviated form of System Management Bus) is a two-wire bus interface through which various system component chips can communicate with each other and with the rest of the system. It is based on the principles of operation of I^2C and was defined by Intel® Corporation in 1995. [SMB, 2000]

After seeing I^2C, it is more clarifying to explain SMBus by highlighting the differences between both interfaces.

Remarkable differences from the electrical side are the voltage level and the supported frequency. Since in I^2C the voltage specifications for low and high logic may vary, in SMBus they are more fixed. SMBus defines low logic as voltages lower than 0.8 V and high logic for higher than 2.1 Volts. V_{DD} ranges from 3 to 5 Volts. The clock frequency range of SMBus is from 10 kHz to 100 kHz, interval that I^2C already covers. SMBus also has a low time-out limit defined at 35ms that I^2C doesn't own.

The protocol used in both interfaces is quite similar. Actually, the Linux Kernel not only has already implemented the necessary functions to manage the transaction through SMBus, but also the functions for I^2C are derived from those ones.

SC16IS740 is compatible with SMBus specifications, and therefore SMBus functions can also be used on it.

3.1.2. UART

The Universal Asynchronous Receiver/Transmitter (UART) is a standard for serial communication. The UART transmitter takes bytes of data and sends them bit to bit in a sequential fashion [OSBORNE, 1980]. On the other node lies another UART collecting those bits to re-assemble them into complete bytes. The transmission has a specific format. It starts with a start bit signal at low logic, followed by a data block. This block can contain from 5 to 9 bits, depending of the configuration. Optionally it can be followed by a parity-bit for detection of possible transmission errors. Finally a high logic stop bit signal indicates the end of the block, and a new one might be send.

Transmission and reception flow through two separate ways (TX and RX). Although the signal is usually carried by an electrical wire, some signaling schemes might also be accomplished using bluetooth, IrDA, optical fiber ...

As the transmission is asynchronous, there is no clock signal sent with the other data. Both UARTs must be configured with the same settings to be able to make a successful communication between them. Those settings are the baud rate, amount of bits that compose a word (from 5 to 9 bits), parity (even, odd or none), number of stop bits (1, 1.5 or 2) and optional flow control.

UART defines the communication protocol, but the voltage signaling depends on the variant used. Some examples are RS-232, RS-422 and RS-485. RS-232 is commonly used in desktop computers referred as COM port. The variant supported by SC16IS740 is RS-485. This standard admits voltage levels from -7 V to +12 V. Positive voltages (higher than +200 mV) are considered logic 1 and negative voltages (lower than -200 mV) are considered logic 0.

3.1.3. UART configuration for the SC16IS740

The SC16IS740 gives enough options in setting the configuration for the UART port:

- **Baud rate** Programmable baud rate
- **Data bits** 5-bit, 6-bit, 7-bit or 8-bit character
- **Parity** Even, odd, or no parity
- **Stop bits** 1, 1.5 or 2
- **Flow control** Optional software and hardware flow control

The SC16IS740 contains a programmable baud rate generator that takes any clock input and divides it by a divisor in the range between 1 and (2^{16} - 1). Setting a bit in a register (prescaler) gives also the possibility of dividing the "divisor" by 4. The equation 3.1 shows how to calculate the divisor for the desired baud rate, and in table 3.3 the required divisors are already calculated for the most common baud rates including the percent error difference with the actual baud rate, considering the 1,8432 MHz crystal integrated in the EB as clock input.

$$divisor = \frac{(\frac{XTAL1 crystal input frequency}{prescaler})}{desired baud rate \cdot 16} \tag{3.1}$$

Let's start with the requirements from the serial port in the thermal camera:

- **Baud rate** 57600
- **Data bits** 8

Desired baud rate	Divisor used to generate 16 clock	Percent error difference between desired and actual
50	2304	0
75	1536	0
110	1047	0.026
134.5	857	0.058
150	768	0
300	384	0
600	192	0
1200	96	0
1800	64	0
2000	58	0.69
2400	48	0
3600	32	0
4800	24	0
7200	16	0
9600	12	0
19200	6	0
38400	3	0
56000	2	2.86

Table 3.3: Baud rates of the SC16IS740 using a 1.8432 MHz crystal [SC1, 2011]

- **Parity** None
- **Stop bits** 1
- **Flow control** None

Using the programmable baud rate generator, to obtain the desired baud rate of 57600 Bd for the thermal camera's port, a divisor with value 2 is required, what results, with a prescaler of 1, a baud rate of 56000 Bd with an error difference of 2,86%, this makes the desired 57600 Bd.

Before setting the divisor in the SC16IS740, it is necessary to enable the divisor latch first by setting the bit 7 of the register LCR (0x3) at high logic and then writing the LSB of the divisor at register DLL (0x0) and the MSB at DLH(0x1). As the prescaler stays with its default value 1, it is not necessary to set it.

According to Table 3.4, in SC16IS740 the register address for LCR is 0x18, the one for register DLL is 0x00, and the address for DLH is 0x08.

#Bit	7	6	5	4	3	2	1	0	
Value	-	A3	A2	A1	A0	CH1	CH0	-	
DLL 0x0	0	0	0	0	0	0	0	0	0x00
DLH 0x1	0	0	0	0	1	0	0	0	0x08
FCR 0x2	0	0	0	1	0	0	0	0	0x10
LCR 0x3	0	0	0	1	1	0	0	0	0x18

Table 3.4: This table set the register address of the different registers used in this section, according to table 3.2 and the register id.

In section 3.1.1 it was established that the address for the SC16IS740 connected to the camera is 1001 001 R/W. As the aim now is to write in the registers and W takes the value 1 in order to

indicate that the master is writing, the address of the slave in hexadecimal is 0x92. As section 3.2.1 explains, when using the SMBus functions, the given slave address must have the LSB bit (the one corresponding to R/W) omitted. The used function will add itself the R or W bit depending if it is a reading or a writing function. Therefore while programming, the given slave address for the thermal camera is 0x49 instead of 0x92.

Start Bit	Slave address	Register Address	Data	Stop Bit
S	92	18	80	P
S	92	00	02	P
S	92	08	00	P

Word length, parity and the amount of stop bits are configurable in the register LCR. According to the requirements from the UART in the thermal camera, the configuration finally must be done sending the following command:

Start Bit	Address	Register Address	Data	Stop Bit
S	92	18	03	P

The last remaining requirement is resetting the Tx and Rx FIFO and afterward enabling it (FIFO mode). This is done by setting at high logic the bits 1 and 2 of the register FCR with id 0x2 and therefore, according to table 3.4, register address 0x10. Enabling the FIFO is done by setting at high logic the bit 0 of the same register. This ends up with:

Start Bit	Address	Register Address	Data	Stop Bit
S	92	10	06	P
S	92	10	01	P

The port settings for the LDS MLR100 are very similar to those for the thermal camera:

- **Baud rate** 19200
- **Data bits** 8
- **Parity** None
- **Stop bits** 1
- **Flow control** None

As happened with the converter chip connected to the thermal camera, in section 3.1.1 it was established that the address for the SC16IS740 connected to the laser distance sensor is 1001 000 R/W. Therefore, the address of the slave when the master writes is in hexadecimal 0x90. When using the SMBus functions, 0x48 will be indicated as slave address.

Besides that, the only difference in the configuration of the UART is the baud rate. As it requires 19200 Bd, it can be obtained using 6 as divisor and a prescaler of 1. Finally configuring all the required settings can be done with the following commands:

Start Bit	Address	Register Address	Data	Stop Bit
S	90	18	80	P
S	90	00	06	P
S	90	08	00	P
S	90	18	03	P
S	90	10	06	P
S	90	10	01	P

3.2. Development of the specific software for controlling both devices

While developing a device driver, it's important to make the distinction between "user space" and "kernel space" [VENKATESWARAN, 2005].

- **Kernel space**. In Linux the machine's hardware is managed in an efficient manner, offering the user a simple and uniform programming interface. In the same way, the kernel, and in particular its device drivers, form a bridge or interface between the end-user/programmer and the hardware. Any subroutines or functions forming part of the kernel (modules and device drivers, for example) are considered to be part of kernel space.

- **User space**. End-user programs are part of the user space. Obviously, these applications need to interact with the system's hardware. However, they don't do so directly, but through the kernel supported functions.

The way the developed software interacts in both spaces is shown in Fig 3.5.
Hereafter follows the development of the necessary software in kernel space and user space.

3.2.1. Character Driver in kernel space

This section focuses in explaining the development of the software in kernel space. This software must act as a bridge between the hardware and the application. For this purpose a character driver that acts like a module device driver was developed.

In Linux, a module device driver can be loaded and unloaded into the kernel using the user commands `$insmod` and `$rmmod` , that use respectively the kernel space functions `module_init` and `module_exit`.

The function `_init` is the responsible for performing some preliminary tasks, like reserving RAM, initializing the device and seamlessly tying the driver to the rest of the kernel via registration functions.

For this certain situation, there are two important structures required in the driver. On the one hand, the `struct file_operations` is typically used to manipulate files. As in UNIX or Linux systems the devices are seen as files that can be open, closed, written and read, it will be used in this case to manipulate the device. On the other hand, it is needed an i2c_client to hold the information of the i^2c device. The kernel already provides some tools collected in the i2c_core to use the i^2c port, and by adding an i2c_driver with probe and detach functions to bind and unbind the device, the communication through the i^2c port will be easily attained.

Therefore it is necessary to attach the file_operations to the character device, and to register an i2c_driver in the i2c_core. The diagram in figure 3.6 shows how the driver remains.

Lastly the function `_exit()` unregisters the device and frees the memory.

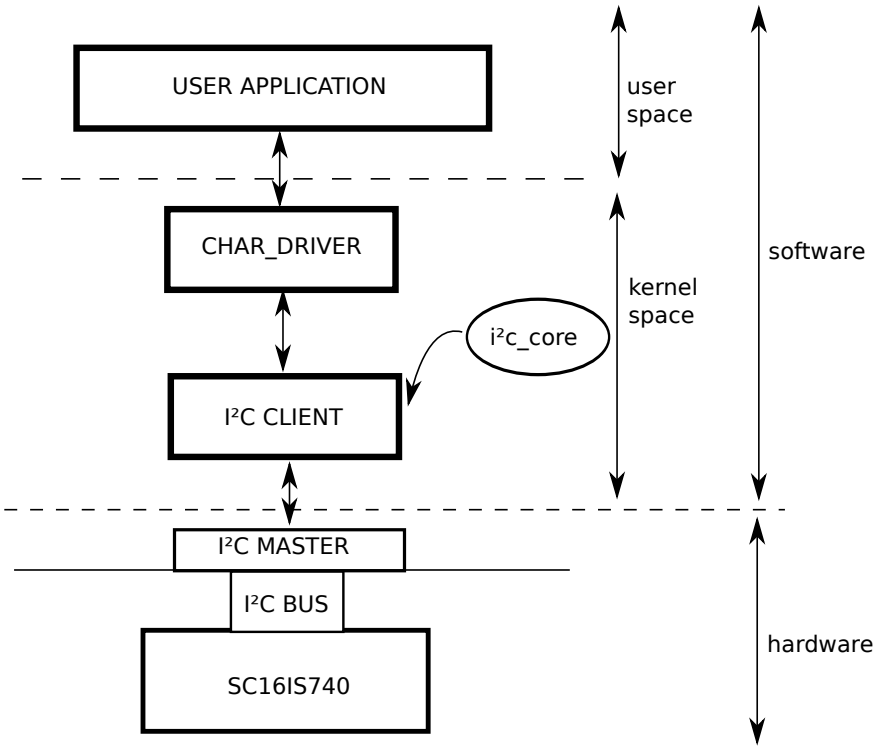


Figure 3.5: Global diagram of the interaction of the different layers in the developed software both in kernel and user space

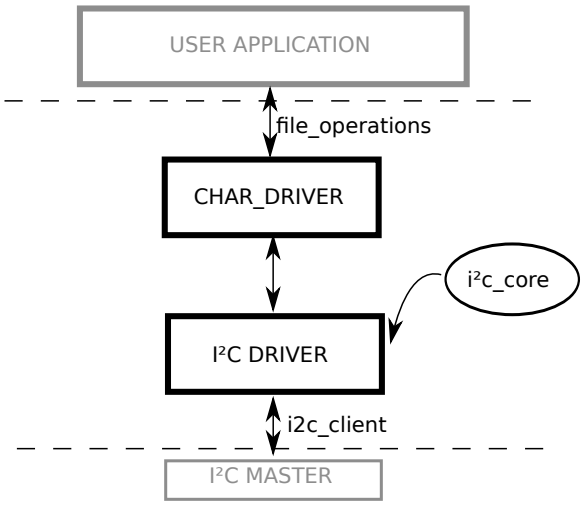


Figure 3.6: Diagram of the driver in kernel space

```
static struct i2c_driver my_driver = {
  .driver = {
    .name = DEVICE_NAME,
    .owner = THIS_MODULE,
  },
  .id_table = sc16is740_id,
  .probe = sc16is740_probe,
  .attach_adapter= sc16is740_attach,
```

```
  .detach_adapter= sc16is740_detach,
};

static struct file_operations my_fops = {
  .open = my_open,
  .release = my_release,
  .read = my_read,
  .write = my_write,
};



static int __init sc16is740_init(void){
  My_Data = kzalloc(BUF_LEN, GFP_KERNEL);
  if (!My_Data) {
    return -ENOMEM;
  }
  Major = register_chrdev(0, DEVICE_NAME, &my_fops);
  if (i2c_add_driver(&my_driver)) {
    printk(KERN_ALERT "Registering I2C driver failed");
  }
}

static void __exit sc16is740_exit(void){
  unregister_chrdev(Major, DEVICE_NAME);
  if (My_Data) {
    kfree(My_Data);
  }
}
module_init( sc16is740_init );
module_exit( sc16is740_exit );
```

On the side of the `i2c_driver`, after its implementation all clients are instantiated from it. There are some important functions of the driver that must be particularly defined.

- The `probe()` function is called when an entry in the `id_table` name field matches the device's name. It receives the matched entry and instantiate that device by filling an `i2c_adapter` structure with the bus number (that is known in this case), and an `i2c_board_info` structure with the device address and driver name. Then it calls `i2c_new_device()`, this way the device will work with the new style i2c driver. In my_info->addr = ADDRESS_KAM;, the address must contain the bits A[7:1]. The LSB corresponding to R/W is omitted because the functions from the i2c_core already add the last bit, depending if it is reading or writing.

  ```
  static int sc16is740_probe(struct i2c_client *client,
    const struct i2c_device_id *id)
  {
    struct i2c_board_info *my_info;
    struct i2c_adapter *my_adap;

    my_info = kzalloc(sizeof *my_info, GFP_KERNEL);
    my_adap = kzalloc(sizeof *my_adap, GFP_KERNEL);
  ```

```
  my_adap->nr = BUS_NUMBER;
  my_adap->id = BUS_NUMBER;

  strncpy(my_info->type,DEVICE_NAME,sizeof(my_info->type));
  my_info->addr = ADDRESS_KAM;

  my_sc16is740->client = i2c_new_device(my_adap,my_info);

  return SUCCESS;
}
```

- The `attach_adapter()` function is called when a new bus is loaded to the system, and checks to see if any I2C device is on this I2C bus to which the client driver wants to attach. In this case it calls the detect function.

```
static int sc16is740_attach(struct i2c_adapter *adapter)
{
    return sc16is740_detect_client(adapter,ADDRESS_KAM,0);
}
```

- The `detect_client()` function probes the given address and fulfills the `i2c_client` data.

```
static int sc16is740_detect_client(struct i2c_adapter *adapter,
  int address, int kind)
{
  my_sc16is740->client->driver = &my_driver;
  my_sc16is740->client->addr = address;
  my_sc16is740->client->adapter = adapter;
  my_sc16is740->client->flags = 0;

  strlcpy(my_sc16is740->client->name, DEVICE_NAME, I2C_NAME_SIZE);

  return SUCCESS;
}
```

- The `detach_adapter()` function is called when the device is unbound, and is responsible of unregistering the I2C device by calling `i2c_unregister_device()` and releasing the memory.

```
static int sc16is740_detach(struct i2c_adapter *adapter)
{
    kfree(adapter);
    return SUCCESS;
}
```

On the other side there is the `struct file_operations` controlling the device as if it were a file. Its functions must be defined as well, and they will be call directly from the user space:

- During the `open()` function, first the module usage count is incremented to protect against removal, then the important information is stored in the `private_data` of the opened file, and the UART configuration for the chip explained in Section 3.1.3 is set. The function config() is detailed in Appendix 1.

```
static int my_open(struct inode *inode, struct file *filep){
  int Minor = inode -> i_rdev & 0xFF;
  try_module_get(THIS_MODULE);
  filep->private_data=(struct sc16is740 *)my_sc16is740;
  config(filep);
  return SUCCESS;
}
```

- In the `close()` function the module count is decremented.

```
static int my_release(struct inode *inode, struct file *filep){
  module_put(THIS_MODULE);
  return SUCCESS;
}
```

- The `read()` function reads from the FIFO of the SC16IS740 using the SMBus function `i2c_smbus_read_i2c_block_data()` and uses `copy_to_user()` to copy the data into the user space.

```
static ssize_t my_read(struct file *filep, char *buffer,
    size_t length, loff_t *offp){
  s32 ret=0;
  int i=0,j=0;
  u8 values[BUF_LEN];

  struct sc16is740 *my_sc = (struct sc16is740 *)filep->private_data;

  if(i2c_check_functionality(my_sc->client->adapter,
    I2C_FUNC_SMBUS_READ_BYTE_DATA)){
    if(length > BUF_LEN)
      length = BUF_LEN;
    ret=i2c_smbus_read_i2c_block_data(my_sc->client,reg_RHR, length, value
    copy_to_user(buffer, (void *)values, ret);
  }
  return ret;
}
```

- The `write()` function gets the data from the user space using `copy_from_user()` and sends it through the i^2c port using `i2c_master_send()`.

```
static ssize_t my_write(struct file *filep, const char *buffer,
    size_t length, loff_t *offp){
  ssize_t data_left=-1;
  unsigned char data[length+1];

  struct sc16is740 *my_sc = (struct sc16is740 *)filep->private_data;

  if(i2c_check_functionality(my_sc->client->adapter,
    I2C_FUNC_SMBUS_WRITE_BYTE_DATA)){
      data_left=copy_from_user((data+1), buffer, length);
      data[0]=reg_RHR;
      i2c_master_send(my_sc->client,data,length+1);
```

Status Byte Value (hex)	Description
0x00	Function executed
0x01	Camera busy processing serial command
0x02	Camera not ready to execute specified serial command
0x03	Data out of range
0x04	Header or message-body checksum error
0x05	Unknown process code
0x06	Unknown function code
0x07	Timeout executing serial command
0x09	Byte count incorrect for the function code
0x0A	Function code not enabled in the current configuration

Table 3.5: Status Byte

```
    }
    return data_left;
}
```

Once the driver is ready, the module is inserted in the kernel using insmod.

As there are two SC16IS740, the driver must be duplicated in the kernel space but with small changes, like the address, the name of the device and the specific configuration required for both attached devices.

3.2.2. User Application for the thermal-camera TAU640

The thermal-camera TAU640 can only recognize commands that follow a specific packet protocol. Out-coming messages are only sent as response of an incoming command, and they also follow the same protocol.

This Serial Packet Protocol starts with the Process Code (0x63) followed by a sequence of bytes with specific meanings.

Byte #	1	2	3	4	5 6	7 8	... N	N+1 N+2
Upper Byte	Process Code	Status	Reserved	Function Code	Byte Count	CRC1	Data	CRC2

The Status Byte is mostly important in the response messages, as it indicates the receipt of the previous incoming message. Its possible values are shown in Table 3.5.

The Function Code (FC) is a byte indicating which command will be executed. Tau 640 Slow Video Camera User's Manual [Tau, October 2010] contains all available functions the camera is able to interpret, i.e. the corresponding Function Byte, Byte Count and the data-range, that the packet is allowed to carry.

The Byte Count (BC) indicates the amount of data bytes sent in the packet. It takes up a total of two bytes, and it must be an even number between 0 and 0x1F4. In case its value is 0, the command will end after the first CRC code.

The cyclic redundancy check (CRC) is an error-detecting code that encodes any incoming block data with the help of a check value with a fixed length using systematic cycle codes. The result has also a fixed length. It is commonly used to detect data corruption caused by noise in transmission channels. The algorithm can be easily implemented as well in hardware as in software. The one used in the camera, and therefore in the program too, is the called

CRC-16-CCITT, which uses as check value the polynomial $x^{16} + x^{12} + x^5 + 1$, represented in hexadecimal as 0x1021. CRC1 is calculated from the first 6 bytes of the packet. CRC2 is calculated from all previous bytes (bytes 1 to N). A list with all available commands for the camera and their valid arguments are shown in Appendix 3 Commands for the TAU640 camera.

Not all possible functions were implemented because they were not considered relevant for the control of the camera on the octocopter. Actually there is still one other possibility not shown in table 3.1 in appendix 3 in case the user wants to send manually a command. It consists in sending to the application as first argument the first part of the command up to CRC1, and as second argument the data, again without the CRC2 code. The application generates both omitted CRC codes and sends the command to the camera. The purpose of this option is to let the sending of commands that are not implemented in the program exempting the user from calculating both CRC.

Transmission is LSB first (for each byte) and most significant byte first on multi-byte messages. All bytes are preceded by a zero start bit and followed by a one stop bit.

For example, when sending 6E the bits should follow the sequence 0 0111 0110 1, this is Start bit, E with LSB first, 6 with LSB first, Stop bit.

The software in user space can interact with some functions implemented in the kernel space of the driver. In this case the functions are `open()`, `read()`, `write()` and `close()`. First it generates the command, verifying that the arguments make sense and there is no error. Once the command is ready to be sent, it opens the device by

```
file = open("/dev/tau640",O_RDWR);
```

As all the functions of the camera are already defined, it is also known the length of the expected answer. Knowing that the FIFO is reset to a variable value each time the device is opened, in order to verify that an answer is received, first of all the FIFO will be read. Afterward the command is sent, and some microseconds later the FIFO is read again. The first read is compared to the second one. In case both are different, the actual answer will be checked by confirming that the status of the camera is the expected (0x00), and checking both CRC codes. In case any of those verifications fails, the message will be sent a maximum of three times until there is a positive answer. Finally the device will be closed.

```
read(file,ini_answer,my_data[ANS].length);
...
if(write(file,my_data[sc].command,my_data[sc].length)==SUCCESS){
...
    read(file,my_data[ANS].command,my_data[ANS].length);
...
}
close(file);
```

3.2.3. User Application for the laser-distance sensor MLR100

The MLR100 laser-distance sensor makes all its communications through the UART port, and only accepts a few specific commands consisting of an only character.

- **Range** (g) - Gets a new range if not sleeping.
- **Sleep** (s) - Goes to lower power mode.
- **Wake up** (w) - Goes to normal power mode.

- **Ready** (r) - Shows that communications are ready, but it needs to be awake to take a new range.
- **Menu** (m) - Displays this menu on the terminal. Also –help can be used for this purpose.

As seen above, the sensor can only take measures while the normal power mode is activated. Because of that, the developed application set the sensor in normal power mode before asking for the measure. After receiving the answer from the sensor, the device is set in lower power mode in order to reduce the consumed power to minimal.

As happened with the driver for the camera, it interacts with the kernel space through the functions `open()`, `read()`, `write()` and `close()`. First it takes the command, verifying if it is one of the list above. In case of identifying the command as "g", a flag will indicate that the device needs to be awaken and put to sleep respectively before and after the main command is sent. To begin the communication with the device it must be opened,

```
file = open("/dev/mlr100",O_RDWR);
```

then the FIFO is read, the character or characters are sent and before closing, the answer is checked to confirm that is valid. In case the answer is not valid, it sends the problematic command again up to a maximal of 3 trials. The final step is to close the communication with the device.

```
read(file,ini_answer,BUF_LEN);
...
if(write(file,&value,(size_t)1)==SUCCESS){
  ...
  read(file,answer,BUF_LEN);
  ...
}
close(file);
```

3.3. Generic Terminal Driver for SC16IS740

The aim of this driver is to act like a bridge between the user space and the UART port of the SC16IS740. In order to make possible to control the device from a terminal program, it is necessary that the software contains a terminal driver. This can be attempted by adding either a uart_driver or a tty_driver. Tty drivers are responsible of providing an interface for terminal style devices, as serial ports or some types of modems [CORBET, 1995]. A uart_driver is a driver derived from tty with specific added features, that optimizes the software for managing UART ports. As seen before in 3.2.1, the software also needs an i2c_client and therefore an i2c_driver to use the SMBus functions from the i2c_core. Furthermore, it is recommended to develop a line discipline for the thermal camera, which would translate the messages into the specific format. Implementing all necessary features together in the same software seems easier using the tty_driver than the uart_driver, as the device is not a pure UART port. Figure 3.7 represents the interaction of the different layers.

The generic driver is confined as a module device driver, and therefore it needs both `module_init` and `module_exit` functions that would be executed when the driver is load and unload into the kernel.

In `module_init` the terminal driver as well as the i2c_driver needs to be registered with the kernel. In order to register the terminal driver with the kernel it is necessary to perform two steps [VENKATESWARAN, 2008]:

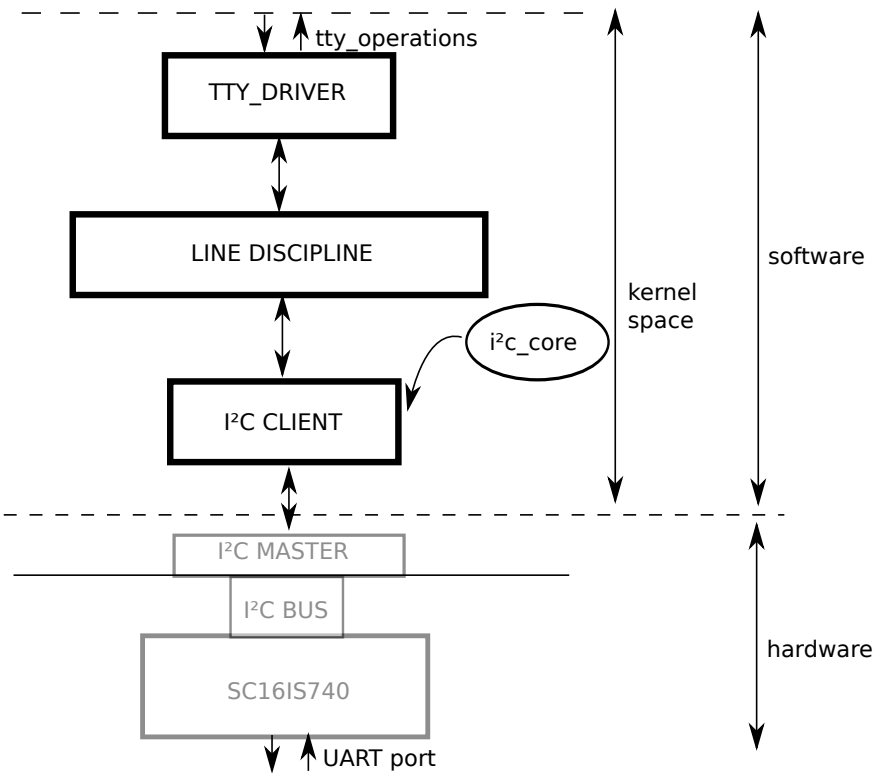


Figure 3.7: Global diagram of the different tools interacting in the generic driver for SC16IS740

1. Call tty_register_driver(struct tty_driver *tty_d); to register itself with the tty core.
2. Register the device with tty_register_device (struct tty_driver *tty_d, unsigned device_index, struct device *device);

Attached to the tty_driver stays the `struct tty_operations` with all the functions associated to the driver [CORBET, 1995]. From all of them, the most important are open, close, write, write_room and set_termios. Anyway, even if not defined, all functions from tty_operations must be declared.

- **open()**: The open function is called when the port is opened. The tty core calls the function with a pointer to the tty_struct assigned to this device, and a file pointer. When this open function is called, the tty driver is expected to either save some data within the tty_struct variable, or save the data within a static array that can be referenced based on the minor number of the port. This is necessary so the tty driver knows which device is being referenced when the later close, write, and other functions are called. This function returns 0 when the opening is a success, and a negative value when an error occurs.
- **close()**: open and close can be called several times, therefore the function should track how many times it has been opened in order to know if it can be closed. It can be performed with a counter associated to the tty driver. This function has no returning value.
- **write()**: This function is called when there is data from the user space that needs to be sent to the hardware. It should use the functions from SMBus to send the data. The returned value is the number of characters that was able to be sent. Negative numbers indicate an error in the function.
- **write_room()**: Returns the number of characters available in the write buffer.

- **ioctl()**: ioctl is the function called for executing operations which are not represented by other function calls. It becomes as second parameter a code number representing the action to perform, and as third parameter either an integer value or a pointer with the necessary data for the action. It can be used for implementing a special line discipline in the driver.

- **set_termios()**: Termios is the struct in the tty_driver that handles the communication parameters. The function set_termios is called when an application tries to set the serial port parameters. In the case of the generic driver for SC16IS740 this function is crucial, as it is the responsible of translating the received parameters into specific orders that change the registers of the chip. For example, when writing set speed 19200 in a terminal program, it must write 0x06 in the register 0x00. The sending is performed using SMBus functions. There are many ways to perform the translation, using a preset table is one of them.

In tty_operation there are no conventional read functions, instead the tty driver is responsible for sending any data received from the hardware to the tty core when it is received. The tty core buffers the data until it is asked for by the user. Because of the buffering logic the tty core provides, it is not necessary for every tty driver to implement its own buffering logic. The tty core notifies the tty driver when a user wants the driver to stop and start sending data, but if the internal tty buffers are full, no such notification occurs. Characters that are received from the tty driver to be sent to the user are added to the flip buffer with a call to tty_insert_flip_char. In order to "push" the data to the user, a call to tty_flip_buffer_push is made.

The implementation of the i2c_driver is the same as the one seen in section 3.2.1. During its implementation it instantiates the i2c_client, later used inside the terminal driver functions for sending data through the I^2C-bus. There are some necessary functions for the correct implementation of the i2c_driver:

- The **probe()** function is the responsible of filling an i2c_adapter structure with the bus number (that is known in this case), and an i2c_board_info structure with the device address and driver name. Then it calls i2c_new_device().

- The **attach_adapter()** checks if any I^2C device is on the I^2C bus to which the client driver wants to attach. In positive case, it calls the detect function.

- The **detect_client()** function fulfills the i2c_client data.

- Finally, the **detach_adapter()** function is responsible of unregistering the I^2C device by calling i2c_unregister_device() and releasing the memory.

As final step, it can be useful to create a line discipline specific for the thermal camera.

A line discipline is responsible for implementing the semantics associated with the device. Depending on user request, it maps the control character to newline, converts lowercase to uppercase, expands tabs, and echoes characters to the associated VT [VENKATESWARAN, 2008]. In the case of the thermal camera it can be used either to attach the CRC code or to actually translate the complicate commands to something easier for the user as the function list in Appendix 3. Each line discipline is identified by a number.

The line discipline can be implemented as part of the kernel or dynamically load it as a module [VENKATESWARAN, 2005]. To register it as a module it is necessary to add in the `module_init` the function tty_register_ldisc(N_TTY, &tty_ldisc_N_TTY). Changing the line discipline from the user space can be done by indicating the number associated to the line discipline in the function `ioctl` from the device driver.

Chapter 4

Results

In order to ensure the correct development of software, different test procedures were applied during the different development phases.

In the early phases of the project, tests were applied by using an oscilloscope in other to check the existence of signals (section 4.1.1). In the next step, EB was connected to a Computer, in order to read and test the outputs (section 4.1.2).

Once the satisfactory results were reached, the tests were run with the actual devices connected to the EB. In the particular case of the thermal camera, a monitor was also connected in order to show in real-time the captured image, and therefore to be able to observe the changes in the pictures while introducing certain commands (section 4.2).

4.1. Preliminary tests

There are different ways to read the messages sent through the SC16IS740. One possibility consists in measuring the voltage in certain pins and connection lines in the hardware. Another more comfortable possibility is to connect the UART to a computer and, with help of the HTerm terminal program, read directly the output data.

Before running any test, the Gumstix Overo System must be loaded. Tests can be perform by connecting the USB connector of the EB with a computer and using a communication software. The required configuration for the communication tool is explained in section 2.2.1.1.

Once the system is loaded, as shown in Fig. 4.1, the driver must be inserted in the kernel using the command `insmod`. With the command `mknod` the character device is linked to the driver, and the application can be loaded. It is necessary to repeat those steps for both devices.

4.1.1. Tests with the help of an oscilloscope

The first step is to check if the driver in kernel space works. This is performed by measuring the voltage level in different pins of the hardware at the EB.

The EB was designed with extra slots that, connected in parallel to the devices, increase the number of possible connections. Figures 4.2 and 4.3 show respectively the back and front general views of the Expansion Board, with the available connections [NEUGEBAUER, 2011]. Extra slots are useful for running tests and connect other devices.

The slots corresponding to the thermal camera are:

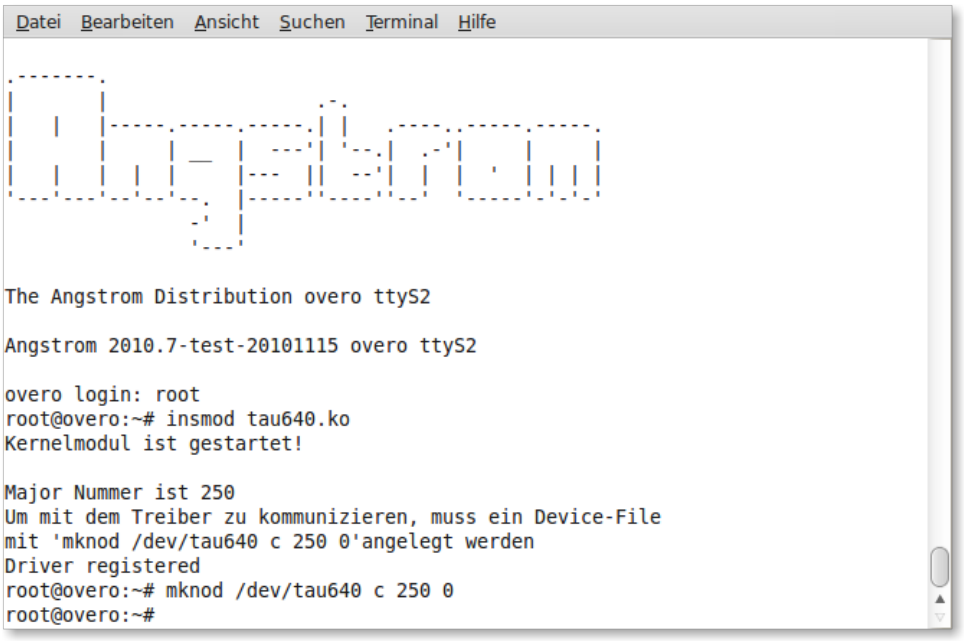

Datei Bearbeiten Ansicht Suchen Terminal Hilfe
The Angstrom Distribution overo ttyS2
Angstrom 2010.7-test-20101115 overo ttyS2
overo login: root
root@overo:~# insmod tau640.ko
Kernelmodul ist gestartet!
Major Nummer ist 250
Um mit dem Treiber zu kommunizieren, muss ein Device-File
mit 'mknod /dev/tau640 c 250 0'angelegt werden
Driver registered
root@overo:~# mknod /dev/tau640 c 250 0
root@overo:~#

Figure 4.1: Loading the Gumstix Overo System

	Thermal camera	
Figure	Name	Functionality
4.3	Video Connector (Thermal-Camera)	actual connector for TAU640
4.3	Analog Video Output (Thermal-Camera)	two-pin connector in parallel to the analog video sent from the camera
4.2	UART-Interface (IR-Camera)	extra UART connector for the configuration

The slots corresponding to the laser distance sensor are:

	Laser distance sensor	
Figure	Name	Functionality
4.2	RS232 Interface (LDS)	actual connector for MLR100
4.3	LDS soldered connection	extra UART connector

	Example of a performed test
Scope:	Verify that the I2C master sends data to the I2C slave.
Procedure:	Measure the signal at the pin 6 (SDA) of the SC16IS740.
Results:	Figure 4.4 shows a measure taken at that pin while receiving data from the computer through the I2C Bus.

4.1.2. Tests connecting the EB to the computer

Once the driver in kernel space is checked, the application must also be tested. In order to perform a more effective debug, the preliminary tests are run connecting the EB to the PC instead of connecting it directly to the device. A terminal program like Hterm (see section 2.2.1.2) emulates the device, and therefore the sent messages are visualized and the answers are controlled in order to test all possible scenarios.

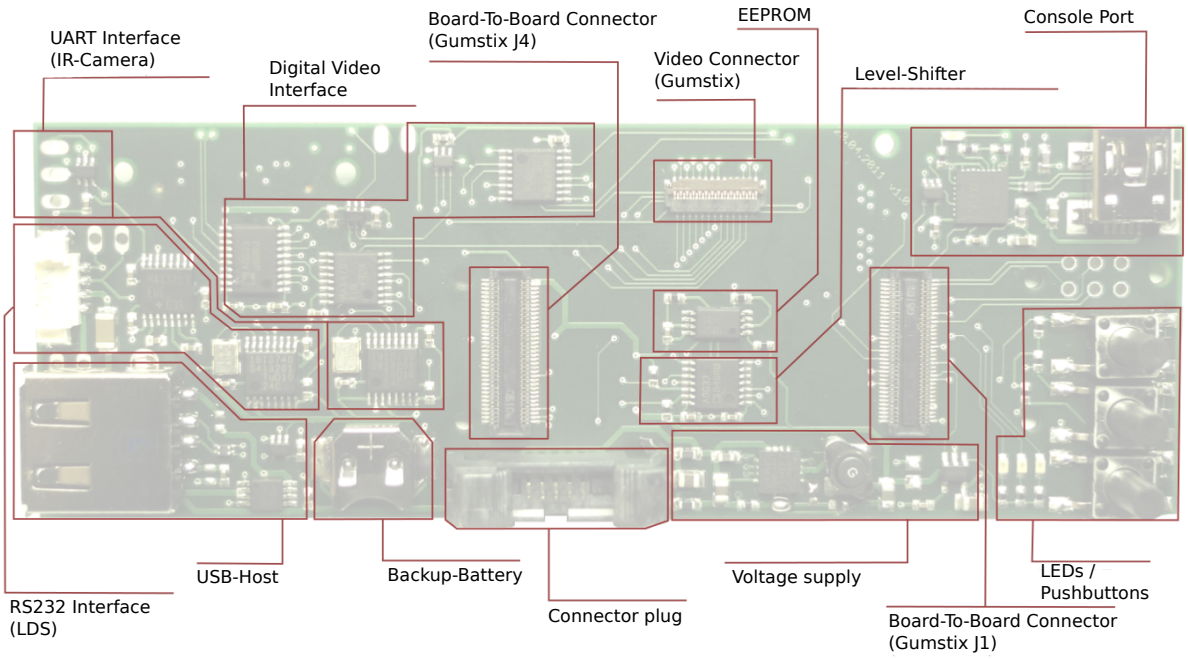


Figure 4.2: General view of the back side of the Expansion-Board. (Source [NEUGEBAUER, 2011])

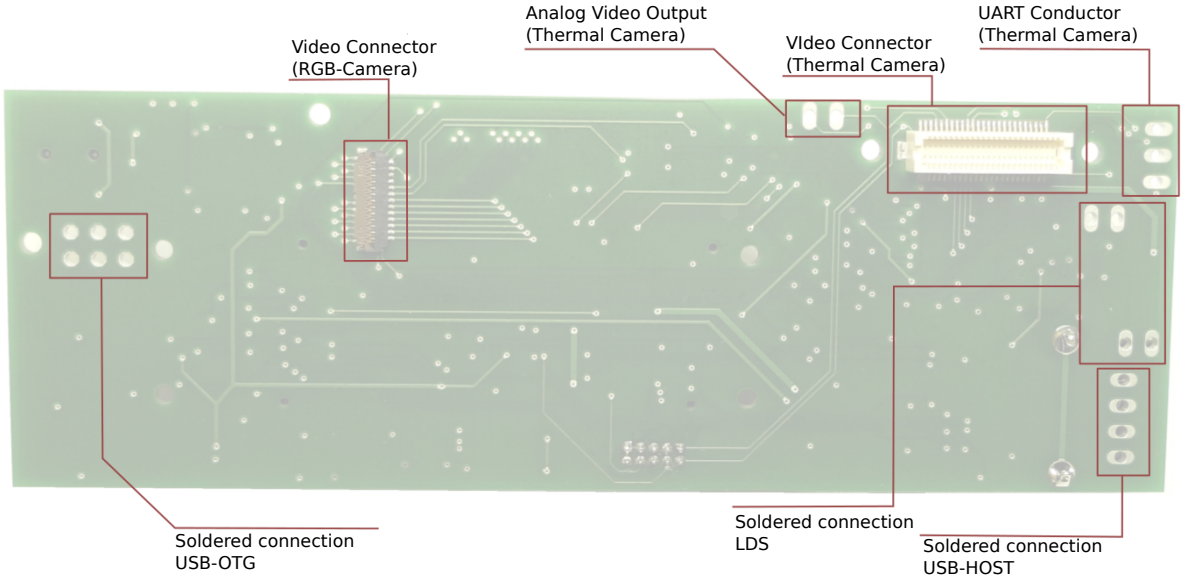


Figure 4.3: General view of the front side of the Expansion-Board. (Source [NEUGEBAUER, 2011])

Before performing the tests, two preliminary tasks are necessary.

1. First it is necessary to connect the extra UART slot to the PC using a UART-USB converter as the one seen in section 2.1.2.

2. Then the terminal program must be configured with the same parameters of the serial port of the device that the program is trying to emulate.

Figure 4.5 shows an example of the data received by HTerm when the application sends certain messages.

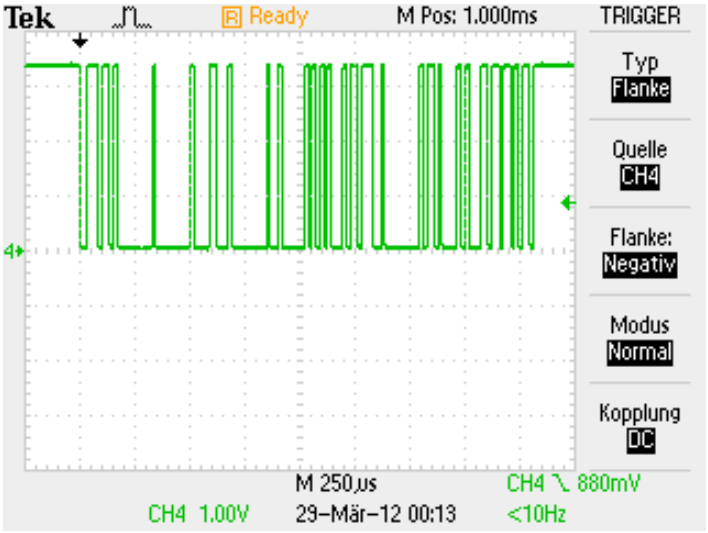


Figure 4.4: Oscilloscope measure at the pin 6 of the SC16IS740 chip while configuring the serial port of the interface.

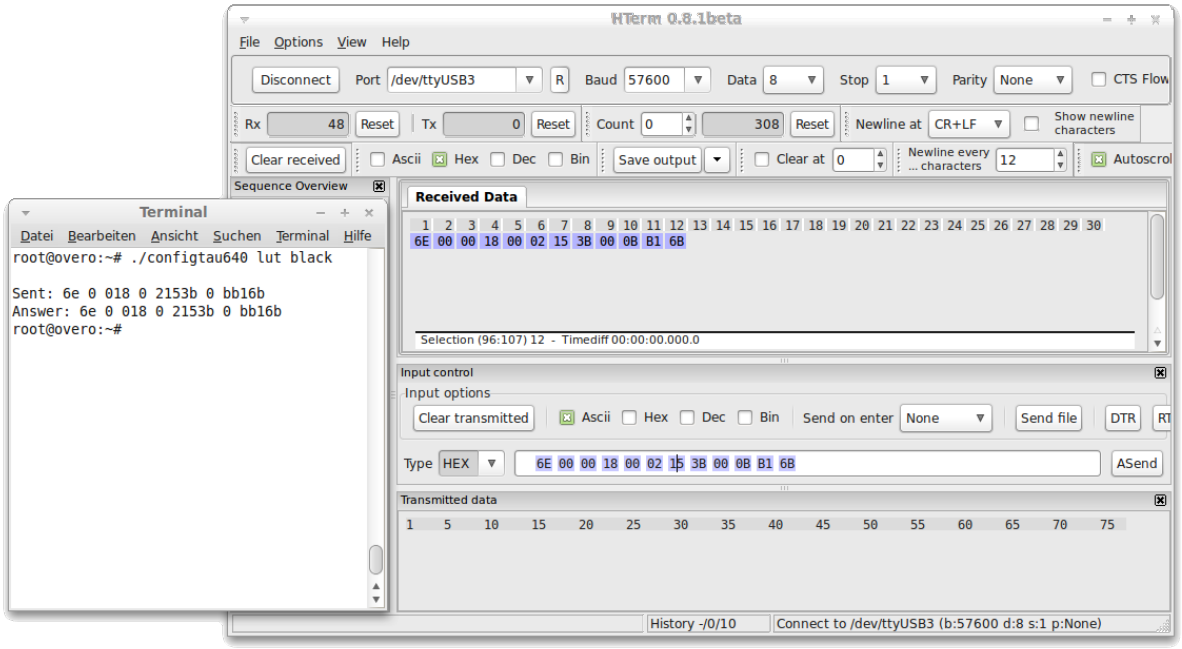

HTerm 0.8.1beta
File Options View Help
Disconnect Port /dev/ttyUSB3 R Baud 57600 Data 8 Stop 1 Parity None CTS Flow
Rx 48 Reset Tx 0 Reset Count 0 308 Reset Newline at CR+LF Show newline characters
Clear received Ascii Hex Dec Bin Save output Clear at 0 Newline every ... characters 12 Autoscrol
Sequence Overview
Received Data
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
6E 00 00 18 00 02 15 3B 00 0B B1 6B
Selection (96:107) 12 - Timediff 00:00:00.000.0
Input control
Input options
Clear transmitted Ascii Hex Dec Bin Send on enter None Send file DTR
Type HEX 6E 00 00 18 00 02 15 3B 00 0B B1 6B ASend
Transmitted data
1 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
History -/0/10
Connect to /dev/ttyUSB3 (b:57600 d:8 s:1 p:None)
Terminal
Datei Bearbeiten Ansicht Suchen Terminal Hilfe
root@overo:~# ./configtau640 lut black
Sent: 6e 0 018 0 2153b 0 bb16b
Answer: 6e 0 018 0 2153b 0 bb16b
root@overo:~#

Figure 4.5: Hterm and a terminal

4.2. Test connecting EB to the actual devices

Once it is confirmed that the commands are sent in the correct format and the application can read the given answers, the tests with the corresponding devices already connected will be prosecuted. The EB is already equipped with suitable slots to directly connect the device without adding any other adapter.

In order to prove the effectiveness of the application for the thermal camera, a screen connected to the analog video output helps to visualize the changes in the captured image when adjusting the parameters of the camera.

In the specific case of the laser distance sensor, the aim is to obtain information, not to change any parameter from the sensor. The best way of checking the application resides in debugging from the software itself, and checking if the received data is correct.

Because of the similarity of both drivers in kernel space, and the greater complexity of the application for the TAU640 compared to the one for the MLR100, the tests were emphasized in the connectors of the TAU640 side. The following section shows an example of how the tests were realized and how it works.

4.2.1. Test connecting EB to TAU640

As explained in section 1.4, the aim of the application for the thermal camera is to make it possible to change certain parameters in order to obtain a useful image. The EB is supplied with extra slots for the analog video output of the thermal camera. By connecting a monitor to this slot it is possible to visualize the changes in the image when sending certain commands to the camera.

The analog video output is a two-wire connection. The data is encoded in a YUV format, that provides the information in terms of the luma (brightness) and chrominance (color). In order to visualize the image, a monitor that supports this format is required.

Once the camera is connected, the monitor is plugged in and the driver is inserted in the kernel, the application can be tested. As seen in Appendix 3, there are many commands that the application acknowledge, so only the crucial ones will be shown as examples in this section.

Appendix 3 contains the functions that the application for the thermal camera TAU640 admits. Besides, there is one more possible kind of argument that the application admits. It consists in introducing manually the code, leaving the places where the check value (CRC) should be calculated as space characters. The application itself calculates the CRC and sends the whole command to the device. The correct generation of the code was already checked while testing the application with the EB connected to the PC. It is necessary now to prove if the camera actually accepts the commands and if the application can read the real answer from the camera.

To run the test it was chosen a command that also requests for information. Let's remember first the Serial Packet Protocol. It starts with the Process Code (0x63) followed by a sequence of bytes, each of them representing a specific feature of the final order.

Byte #	1	2	3	4	5 6	7 8	... N	N+1 N+2
Upper Byte	Process Code	Status	Reserved	Function Code	Byte Count	CRC1	Data	CRC2

In the TAU640 User Manual [Tau, October 2010] there is a table with all the functions allowed, its corresponding Function Code (FC), Byte Count (BC) and admissible range of data. Taking as example the function that gets the optimization image mode, called AGC_TYPE, its Function Code is 0x13 and the Byte Count is 0. The first argument sent to the application (called configtau640) consists in the message until the first CRC (i.e., bytes 1 to 6). Conforming the message as seen above, it results 6E00001300. Byte Count indicates the amount of data bytes. In this case as there are no data bytes sent (BC is 0), the second argument sent to ./configtau640 is 0.

```
 root@overo# ./configtau640 6E00001300 00
Sent: 6e 0 013 0 0c588 0 0
Answer: 6e 0 013 0 2e5ca 0 22042
```

According to the User Manual, the answer received indicates that the status of the camera is "ready", the FC is 0x13 (AGC_TYPE) and the answer contains 2 data bytes. The data bytes

conforming 0x0002 has the meaning, according to the manual, that the optimization image mode set on the camera is the one denominated “auto bright”.

Another performed test consists in sending a certain command that changes the parameter of the image. One function that is easily detected at first sight is the contrast function. Figure 4.6 helps to visualize the difference between three different contrast values in the image captured by the camera.

```
 root@overo# ./configtau640 contrast 100
Sent: 6e 0 014 0 2605a 0642c22
Answer: 6e 0 014 0 2605a 0642c22
```

Figure 4.6: From left to right, captured image with contrast 20, 50 and 70

4.2.2. Test connecting EB to MLR100

Opposite to the thermal camera, the effectiveness of the application for the laser distance sensor cannot be visualized. Fortunately the main reason the software for the sensor is developed for, is to obtain the distance measure. Checking the correct operation of this feature is enough to consider that the application works.

The test was carried out by assembling the laser to the EB, inserting the driver and using the application to ask for the measured distance. Knowing the real distance in advance, the next step is to compare it to the given answer. As example, the sensor was positioned 2 meters away from a wall, pointing directly to it. The following code was the result of executing the application:

```
 root@overo# ./mlr100 g
2.04m
```

Appendix 4 contains a list with all the commands that the laser distance sensor application accepts. Another command that can be tested is the one setting the power mode. The only way to make sure which power mode is set, is by measuring the power and comparing the energy consumption in both power modes. The energy consumption can be calculated either using a wattmeter or measuring the voltage as well as the current and multiplying them.

Chapter 5

Conclusion and outlook

The main scope of the master thesis was to develop a software capable of establishing a communication with the serial port of the thermal camera and the laser-distance sensor. Physically the communication flows from the serial port of the device to an interface that converts from UART to I^2C. The interface is then connected to the computer-on-module through an I^2C-bus. Figure 5.1 represents this connection.

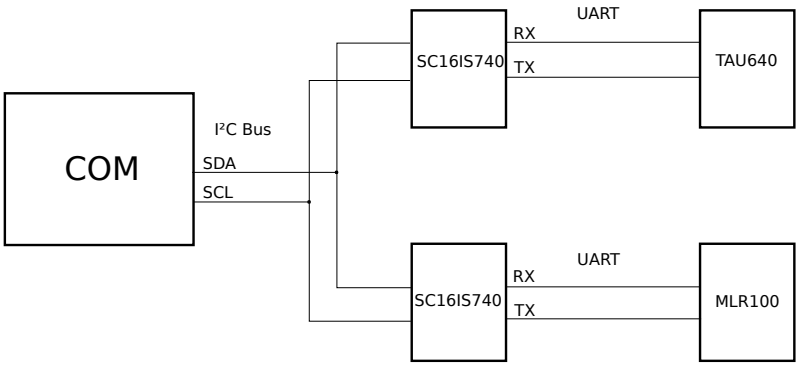


Figure 5.1: Connection between the COM and the devices through the SC16IS740 interface

The first section of the chapter analyzes the product developed during this project. The second section contains possible improvements of the product, that can be done in future developments.

5.1. Analysis of the developed software

The driver shall be able to communicate with the thermal camera and the distance sensor. Through the communication made possible by the driver, the COM shall be able to:

- optimize the parameters that define the captured image of the thermal camera, in order to obtain an image that can be analyzed to detect the fawn deer.
- verify the accuracy of the Google Maps Elevation API used by the autopilot of the UAV. The COM shall be able to read the measures of the distance sensor, so the actual distance to the ground can be known.

The software needed to fulfill this requirements, shall be able to be executed in the computer-on-module. The COM runs a Gumstix Overo System with a Linux Kernel. Although it is possible to compile code directly in Gumstix, for practical reasons the software was developed

in a PC and later executed in the COM. For this purpose, a special software environment was required in order to build compatible executables with Gumstix.

In order to prosecute the tasks and accomplish the requirements, the following software was developed:

- A character driver inserted in the kernel. This driver is responsible of:
  - establishing the connection with the SC16IS740 through the I^2C bus
  - setting the configuration for the serial port, and
  - defining the necessary functions to be accessed from an application in the user space.
- An application personalized for each device that lets the user communicate automatically with the device.

Figure 5.2 shows the layers of the developed software.

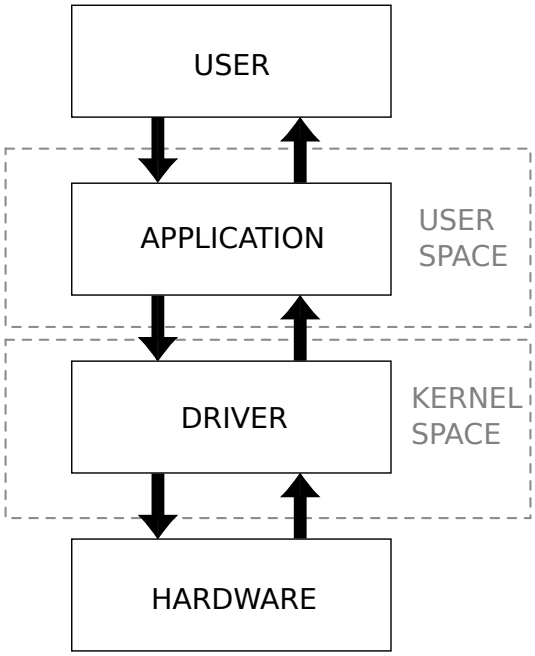


Figure 5.2: Diagram of the layers in the developed software

As seen in Chapter 4, both developed software perform the required tasks. Therefore, the requirements of this project were fulfilled.

5.2. Possible future improvements

The drivers were specifically developed for the thermal camera TAU640 and the laser-distance sensor MLR100. On the one hand, personalizing the software has as advantage that it is optimal developed for the use of this specific hardware. On the other hand, it can be a problem if in a future the device is removed and substituted by another one with different characteristics.

There are three possible solutions to solve this problem:

- While developing the required applications, a generic application that sends any message without codification and reads the whole buffer of the SC16IS740 was developed. One possibility is to use this application. The driver inserted in kernel space can remain, but it might need to be modified in order to adjust the serial configuration to the specific port settings of the new device. Appendix 1 explains how to perform it.
- Another option is to create a new application specific for the device. Again, the driver in kernel space might need to be modified in order to update the new configuration for the serial port. A guide to build an application for the driver is detailed in Appendix 2 and Appendix 1 explains how to configure the serial port at the SC16IS740.
- The last option to solve this problem is to develop a new generic terminal driver for the SC16IS740 as explained in section 3.3. Since the driver contains a tty_driver, the device can be accessed using a terminal program (see section 2.2.1). Therefore, it is not necessary to develop an application in order to establish a communication with the device.

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PART II

USER MANUAL

Chapter 1

How to configure the settings of the serial port in the driver

In the driver in kernel space, the only part of the code that depends on the attached device are the settings for the serial port.

The configuration of the serial port is performed by setting certain values in the registers of the SC16IS740 interface. A list with the description of the internal registers and the bit settings can be found in the product data sheet of the chip [SC1, 2011].

It might be necessary to highlight that the id of the internal registers in that list does not directly correspond with the register address. In order to obtain the register address, the table 1.1 must be applied, where A[3:0] correspond to the register id.

Bit	Name	Function
7	-	not used
6:3	A[3:0]	UART's internal register select
2:1	CH1, CH0	channel select: CH1 = 0, CH0 = 0 Other values are reserved and should not be used.
0	-	not used

Table 1.1: Register address byte for the internal registers in SC16IS740 [SC1, 2011]

In section 3.1.3 it is explained the obtaining of the necessary commands for configuring the serial port for the thermal camera TAU640 as well as for the sensor MLR100.

Before going directly to the code, a brief explanation about how the driver was programmed can help to understand better what follows. The developed driver has two essential parts:

- An i2c_driver with an attached i2c_client that helps with the communications through the I^2C bus.
- A character driver with an implemented struct file_operations, that enables the communication with the user.

The configuration is performed in the function config() inside the driver. This function is called from open(), that belongs to the struct file_operations of the char_driver. Open() is called from the user space when opening the device, and it is mostly used to store important data of the driver in the variable file. The code of the function config() is :

```
static void config(struct file *filep)
{
```

```
        char data[2];
        struct sc16is740 *my_sc = (struct sc16is740 *)filep->private_data;

        data[0] = 0x18;
        data[1] = 0x80;
        i2c_smbus_write_byte_data(my_sc->client, data[0],data[1]);

        ....
}
```

As brief explanation about the code, one of the components in struct sc16is740 is an i2c_client. While implementing the i2c_driver in the kernel, an i2c_client was created. This client is necessary in all SMBus functions, therefore it is saved within the struct file in order to be able to retrieve the data in all file_operations functions.

The function i2c_smbus_write_byte_data() receives as second argument the register address and as third the byte that must be written in the aforementioned register.

Chapter 2

How to create an application for the driver

First of all, the application should be compiled with the cross compiler in order to make sure the execute file is compatible with the Gumstix System. In case of using the OE cross compiler, the Makefile must include:

```
OVEROTOP ?= /home/USER/overo-oe
CROSS_COMPILE ?= $(OVEROTOP)/tmp/sysroots/i686-linux/usr/armv7a/bin/
      arm-angstrom-linux-gnueabi-
```

Once the application is ready to be compiled, it can be performed by executing `$make` in the directory where the application is located. This directory should be inside the user.collection main directory of the cross compiler. (More information about the cross compiler can be found in section 2.2.4 and [GUMSTIX, 2011a]).

The best way to show how to create an application is with an example. The following code represents a simple application, that just opens and closes the device:

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <unistd.h>
#include <sys/types.h>
#include <sys/stat.h>
#include <fcntl.h>

int main ( int argc, char *argv[] )
{
      int file = open("/dev/device",O_RDWR);
      close(file);
      return 0;
}
```

But only opening and closing the device is useless. As it was already explained in section 3.2.1, thanks to the char_driver inside the device driver, it behaves like a file. The user can `open`, `close`, `write` and `read` the device as if it were a file. The function `ioctl` can be also implemented in the driver. It is used to attend orders that are not collected in the `file_operations` functions.

The function used for writing is `size_t write(struct file *,const char *,size_t)`. It takes as first argument the struct file obtained when opening the device. Second argument is the data that is going to be sent. The last argument contains the size of this data.

Reading is performed by the function `size_t read(struct file *,char *,size_t)`. Again, the first argument contains the file. The second argument is a pointer to the read data from the FIFO buffer. The last argument indicates the amount of data bytes requested.

The application can receive arguments when loaded. In function main(), `argc` indicates the amount of argument received, `*argv[]` is a pointer to the aforementioned arguments. Other way to communicate with the user is through functions like `printf` and `scanf`. This way the application receives and works on the data from the user. Then, it sends orders to the driver in kernel space, that finally interacts with the hardware.

Chapter 3

Commands for the TAU640 camera

Beside the commands of table 3.1, there is another available possibility in case the user wants to send manually an order. It consists in sending to the application as first argument the first part of the command up to CRC1, and as second argument the data, again without the CRC2 code. The application generates both omitted CRC codes and sends the command to the camera. The purpose of this option is to let the sending of commands that are not implemented in the program exempting the user from calculating both CRC.

Text in bold in table 3.1 represents the recognized arguments by the application.

It is remarkable the special case of the function freestring, that sends as direct order the following argument. A correct order using this function is:

```
root@overo# ./configtau640 freestring 6e0000140002605a00642c22
```

Command	Description	Argument	FC	BC
agc_filter	Sets the AGC ITT filter value	**0 - 255**	0x3E	0x2
agc_type	Sets the image optimation mode	**plateu** **once** bright **auto** bright **manual** **linear**	0x13	0x2
brightness	Sets the manual brightness value	**0 - 16383**	0x15	0x2
brightness_bias	Sets the brightness bias value in the auto bright mode	**-2048 - 2048**	0x15	0x2
contrast	Sets the manual contrast value	**0 - 255**	0x14	0x2
dde_gain	Sets the gain of the DDE filter	**0 - 255**	0x2C	0x2
dde_threshold	Sets the threshold of the DDE filter	**0 - 255**	0xE2	0x2
digital_output	Sets the digital output channel mode	**0** = 14-bit data **1** = 8-bit data **2** = digital off **3** = 14-bit unfiltered **4** = 8-bit inverted **5** = 14-bit inverted **6** = 14-bit inv. unfilt.	0x12	0x2
do_ffc	short FFC or a long one	**0** = short **1** = long	0x0C	0x0
factory_reset	Resets camera with factory header values	-	0x03	0x0

Command	Description	Argument	FC	BC
freestring	Sends the argument	command (**6E00..**)	-	-
iit_mean	Sets the ITT midpoint offset	**0 - 255**	0x55	0x2
max_agc_gain	Sets the max value of video gain	**0 - 2048**	0x6A	0x2
plateu	Specifies the Plateau level for Plateau AGC	**0 - 1000**	0x3F	0x2
reset	Reset to default modes	-	0x02	0x0
set_default	Restore settings as power-on values	-	0x01	0x0
spot_meter_mode	Sets the spot-meter mode	**on** = ° C scale **off** = disable	0x1F	0x2
test_**pattern**	Sets the test pattern mode	test pattern **off** **asc**ending ramp **big** vertical **hor**izontal shade **color** bars ramp with **step**s	0x25	0x2
video_**lut** **polarity**	Sets the analog video LUT or intensity transform	white black fusion rainbow globow ironbow1 ironbow2 sepia color1 color2 ice_fire rain OEM red green	0x10	0x2
XP **bus**_mode	Set the XP bus mode	**0** = Gen. Bus **1** = BT656	0x12	0x2

Table 3.1: Table with the available function commands in the application for the TAU640 camera

As example, changing the analog video LUT to sepia can be performed by writing:

```
root@overo# ./configtau640 lut sepia
```

Chapter 4

Application for the laser-distance sensor MLR100

The aim of this application is to establish the communication between the user and the laser-distance sensor. Table 4.1 collects all the commands the sensor admits. The most important ones for the project are:

- **Range** Gets the distance measured by the sensor. This is useful to verify the accuracy of the Google Maps Elevation API and get the real distance to the ground.
- **Sleep** The sensor goes to lower power mode. This is useful to save battery and increase the flight autonomy.

The application only admits one argument. If there are more, all of them but the first one will be ignored.

Command	Name	Description
g	Range	Gets a new range if not sleeping.
s	Sleep	Goes to lower power mode.
w	Wake up	Goes to normal power mode.
r	Ready	Shows that communications are ready, but it needs to be awake to take a new range.
m	Menu	Displays this menu on the terminal. Also –help can be used for this purpose.

Table 4.1: Arguments admitted by the application for the laser-distance sensor MLR100

An example of how to execute the application:

```
root@overo# ./mlr100 g
```

DOCUMENT II

PROJECT BUDGET

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Chapter 1

Measurements

This chapter gathers a list of components and equipment used during the project, as well as the attributable hours to the project.

1.1. Final product

Product	Company	Units
TAU640	FLIR Systems	1
MLR100	Aerius Photonics	1
MLR100 Interface Board	Aerius Photonics	1
SC16IS740	NXP	2
Overo Sand COM	Gumstix	1

1.2. Test environment

Product	Company	Units
ELV USB-I2C	ELV	1
TTL-232R-PCB	FTDI Chip	1
SC16IS740	NXP	1
Monitor		1

1.3. Software

Program	Amount	Hours of work (project)
HTerm	1	150
C-Kermit	1	260

1.4. Equipment and tools

Element	Amount	Hours of work (project)	Hours of work (year)
Computer	1	1000	1600
Oscilloscope 4 channels	1	10	300
Multimeter	1	20	300
Soldering iron	1	30	300
Solder sucker	1	15	150

1.5. Labor

Activity	Hours
Initial tests	50
Programming	300
Hardware implementation	70
Tests and problem solving	150
Writing documentation	150
Total:	720

Chapter 2

Unit prices

This chapter gathers the unit price of every product used during the project.

2.1. Final product

Product	Price (€/unit)	Shipping (€)
TAU640	11,999.99	-
MLR100	1,885.72	-
MLR100 Interface Board	381.68	-
SC16IS740	1.23	7.33
Overo Sand COM	86.92	-

2.2. Test environment

Product	Price (€/unit)	Shipping (€)
ELV USB-I2C	24.95	4.95
TTL-232R-PCB	15.15	17.25
SC16IS740	1.23	7.33
Monitor	50.00	-

2.3. Software

Program	Price (€/unit)
HTerm	0.00 (Freeware)
C-Kermit	0.00 (Freeware)

2.4. Equipment and tools

Element	Price (€/unit)
Computer	799.00
Oscilloscope 4 channels	1,580.00
Multimeter	45.00
Soldering iron	35.00
Solder sucker	35.00

2.5. Labor

Activity	Price (€/hour)
Initial tests	12.00
Programming	12.00
Hardware implementation	12.00
Tests and problem solving	12.00
Writing documentation	12.00

Chapter 3

Partial summation

This chapter gathers the partial costs of the elements conforming each entry, that were calculated by the measurements and unit prices.

3.1. Final product

Product	Units	Price (€/unit)	Shipping (€)	Total cost (€)
TAU640	1	11,999.99	-	11,999.99
MLR100	1	1,885.72	-	1,888.86
MLR 100 Interface Board	1	381.68	-	381.68
SC16IS740	2	1.23	7.33[1]	2.46
Total:				14,272.99

3.2. Testing environment

Product	Units	Cost per unit (€)	Shipping (€)	Total cost (€)
ELV USB-I2C	1	24.95	4.95	29.90
TTL-232R-PCB	1	15.15	17.25	32.40
SC16IS740	1	1.23	7.33	8.56
Total:				70.86

3.3. Software

Product	Units	Price (€/unit)	Total cost (€)
HTerm	1	0.00 (Freeware)	0.00
C-Kermit	1	0.00 (Freeware)	0.00
Total:			0.00

3.4. Equipment and tools

In order to calculate the attributable cost of the equipment and tools, it was considered that the typical amortization period is 4 years and it was distributed in aliquot parts according to hours of work.

[1] Shipping cost is already considered in Test Environment

Element	Amount	Hours of work (project)	Hours of work (year)	Price (€/unit)	Amort. (%)	Cost (€)
Computer	1	1000	1600	799.00	25%	124.84
Oscilloscope	1	10	300	1,580.00	25%	13.17
Multimeter	1	20	300	45.00	25%	0.75
Soldering iron	1	30	300	35.00	25%	0.88
Solder sucker	1	15	150	35.00	25%	0.88
Total:						140.52

3.5. Labor

Activity	Hours	Price (€/hour)	Cost
Initial tests	50	12.00	600.00
Programming	300	12.00	3,600.00
Hardware implementation	70	12.00	840.00
Tests and problem solving	150	12.00	1,800.00
Writing documentation	150	12.00	1,800.00
Total:			8,640.00

Chapter 4

General budget

Adding the contribution of all previous entries, the total cost of the project amounts to:

Entry	Cost (€)
Final Product	14,272.99
Testing environment	70.86
Software	0.00
Equipment and tools	140.52
Labor	8,640.00
Total:	23,124.37